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ABSTRACT

This document tries to answer some of the most frequently asked questions about the teaching and learning of science in order to provide parents and community leaders a base of information to help improve science education. Questions are posed in three major areas: science in American education; science in the classroom; and science in the home and community. Questions involving science in American education address the issues of the importance of science, the need for change, new directions in science education, and systemic reform. Questions involving science in the classroom address the issues of essential science skills and knowledge needed by students; student attitudes and motivation; equity for female, minority, limited English proficient, and disabled students in science; instructional methods that promote science learning; instructional materials; improved assessment methods; teacher requirements and needs; and teacher and community collaboration. Questions involving science in the home and community address the issues of parental attitudes; parent involvement; and community and business involvement. Additional resources provided include a list of 8 major reports and studies produced by scientific, education, and business groups, and 73 references listed alphabetically and by section. (MDH)

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# What We Know About Science Teaching And Learning

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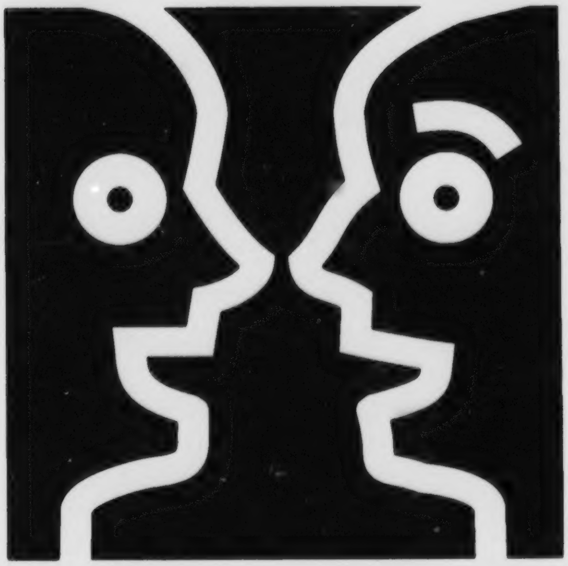

# What We Know About Science Teaching And Learning

By Nancy Kober

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Dear *EdTalk* Reader:

This publication tries to answer some of the most frequently asked questions about the teaching and learning of science.

The far-sweeping goals our nation has established in science instruction cannot be met by educators working alone. Reforms demand a broad constituency. Parents, community leaders, and leaders from business and industry have to understand why science education must change, what directions of change are the most promising, and what roles they might play in it.

The Council for Educational Development and Research established the *EdTalk* publication series two years ago as a means of informing a variety of audiences about nationally significant topics in education. This particular issue, however, is a collaboration between two organizations: The Council for Educational Development and Research and the Triangle Coalition for Science and Technology Education.

The Council consists of some of the foremost educational research and development institutions in the country, including the national network of regional educational laboratories. These institutions build the most recent and best educational research findings into school programs and practices. They are committed to an approach to change in which local and state educators and local communities are the key decision makers in the development of improved education for schools and students.

The Triangle Coalition is made up of more than 100 members with representation from business, industry, and labor organizations; scientific and engineering societies; education associations; and governmental agencies. Its network of several hundred action groups — called alliances — is engaged in connecting the national thrusts for reform to the local schools and school districts where reform must be implemented.

By summarizing some of what we have learned in question and answer format, we aim to provide a base of information for citizens who want to help improve science education, whether their role is in the school, the home, the business community, or in a local service organization. We see this document as a starting point from which interested readers can join the effort to reform science education in our schools.

Sincerely,

Dena G. Stoner
Executive Director
Council for Educational
Development and Research

Sincerely,

John Fowler
Executive Director
Triangle Coalition for Science
and Technology Education

# TABLE OF CONTENTS

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## Science in American Education

Science Matters .......... 3
The Need for Change .......... 4
Promising Directions .......... 6
Systemic Reform .......... 8

## Science in the Classroom

Essential Science Learning .......... 13
Attitudes and Motivation .......... 21
Equity .......... 26
Instructional Methods .......... 36
Instructional Materials .......... 52
Assessment .......... 57
Teachers .......... 63
Teacher and Community Collaboration .......... 67

## Science in the Home and Community

Parent Attitudes .......... 71
Parent Involvement .......... 73
Community Involvement .......... 77
Business/Community Involvement .......... 81
Additional Resources .......... 82

References .......... 85

# What We Know About Science Teaching And Learning

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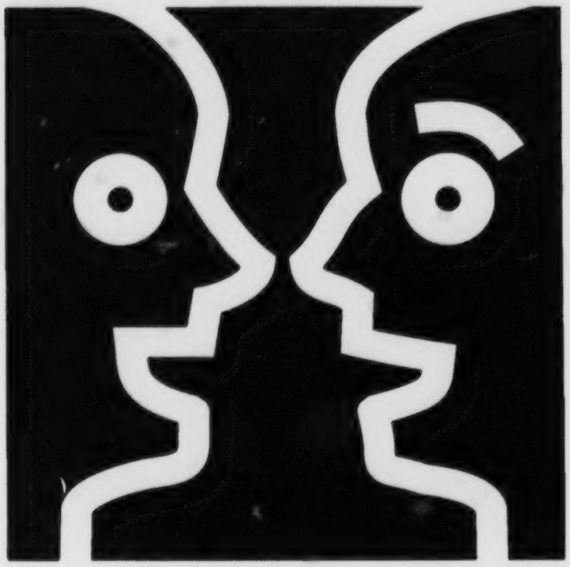

## Science in American Education

# *Why is science education so important?*

Science and technology are powerful forces that shape human life on earth. They have enormous potential to make our lives better and richer, to keep our world safe and liveable, and to make our society productive and progressive. Science education needs to help fulfill the potential of science and technology by ensuring that they are used effectively, creatively, and wisely.

Although recent public debate has focused largely on the economic reasons for why science education is important, many scientists and researchers feel that other reasons are even more compelling. The first reason is personal fulfillment. The study of science enriches people's lives. Science lights the dark and frightening corners of the world. It opens the human mind to new aesthetic and intellectual pleasures and to a new appreciation of the beauty and precision that surrounds them. Science education empowers people to take greater control of their lives and to face problems with courage and understanding. It liberates them to imagine new questions and to set about finding new answers.

***Although recent public debate has focused largely on the economic reasons for why science education is important, many scientists and researchers feel that other reasons are even more compelling.***

The second reason is the welfare of society. All citizens need to be scientifically literate to function effectively in an increasingly technical age and to help create and sustain a decent, just, and vigorous society. A scientifically literate person is one who understands the key concepts and principles of science and uses scientific knowledge and ways of thinking in everyday life. Citizens today face a range of hard choices — from the personal, such as how to avoid contracting AIDS, to the global, such as what to do about acid rain. People who understand science are better prepared to sort fact from myth, make sensible decisions, and urge their leaders toward enlightened public policy choices.

The third reason for science education being so important is economic. The nation will continue to need well-educated scientists, engineers, and technicians to push the envelope of knowledge and rekindle the spirit of invention and discovery that built our nation. We will also need people who are scientifically literate in a range of fields, including those that are not ostensibly scientific or technical. New technological and workplace demands are increasing the need for workers who have flexible skills, a basic grasp of science and technology, and the ability to solve problems and to think critically.

# Why do we need to change the way science is taught and learned?

Most schools use a conventional approach to teach science. Science is presented as a fixed body of facts, principles, and definitions, ordered sequentially and segregated by discipline and topic. Learning is dispensed by the teacher and the textbook, with students expected to master a range of topics by listening and reading. Instead of acquiring understanding in context, students learn isolated bits of knowledge, or "factoids": Name the noble gases. Point to the ribosomes in a drawing of a cell. Give the formula for calculating density.

This conventional approach to science education is not working for most students. Scientists, researchers, educators, and business people agree on this point, and the evidence supports their perceptions.

Most adult Americans are not scientifically literate. According to one recent poll, one-half the public did not know that the earth revolves around the sun once a year, and one-half mistakenly believed that early humans lived at the same time as the dinosaurs.

***According to one recent poll, one-half the public did not know that the earth revolves around the sun once a year, and one-half mistakenly believed that early humans lived at the same time as the dinosaurs.***

Of particular concern are the generations now moving through the educational system or through young adulthood. Two decades of data from the National Assessment of Educational Progress (NAEP) — a federally funded project that measures changes in student achievement in key subjects — show that despite upturns in 1980s, the average science achievement scores of students at ages 13 and 17 remain below 1969 scores. The achievement of nine-year-olds is about where it was in the 1970s. Recent increases only offset an earlier drop.

Although international assessments are fraught with methodological problems and limited in their ability to compare different cultures, the low to middling ranking of U.S. students in these studies corroborates the need to improve science education for all students.

Even if one leaves aside international comparisons, statistics on U.S. students' progress through the science pipeline — the channel that leads from elementary science through secondary school courses, and on to college majors and careers in science, engineering, and technology — point to serious problems. Somewhere in the middle grades, most U.S. students lose interest in science. By high school, many students of all achievement levels find science difficult, boring, and irrelevant. Fifty-five percent of students do not complete a chemistry course and 80 percent do not take physics. A disproportionate share of these students are girls, minorities, and non-college-bound youth. Schools may even treat more advanced courses as filters, discouraging all but high-achieving students and those with an expressed interest in scientific and technical careers from continuing science studies.

***Moreover, most schools do not even truly consider science a core subject.***

The result is that only a slim percentage of young people graduate with the knowledge, skills, and motivation that constitute scientific literacy, let alone with the background to successfully tackle college science or pursue science-related careers.

According to many researchers, scientists, and educators, these troubling statistics are symptomatic of the weaknesses in the conventional approach to science education — an approach that emphasizes breadth over depth, seatwork over activity, memorization over critical thinking, and recitation over well-reasoned argument. Moreover, most schools do not even truly consider science a core subject. In many elementary classrooms, science has all but vanished from the curriculum. According to a 1986 NAEP study, more than two-thirds of third-grade teachers reported spending two hours or less per week on science. And as the aforementioned statistics on enrollments in advanced courses show, high schools do not view science as a basic for all students.

Partly, science does not receive the attention it warrants because teachers themselves do not feel comfortable teaching science and have not received the preparation and inservice training they need to become proficient science teachers. But it is hardly fair to blame teachers for a problem that is much more endemic. Teachers have numerous competing demands on their time, including competition from other areas of education that receive greater support and attention from school administrators, parents, the public, and society.

For all of these reasons, groups of educators, scientists, business leaders, and researchers have independently concluded that the time is ripe for a comprehensive redesign of science education so that it begins in kindergarten and continues uninterrupted through grade 12.

# What are some of the most promising new directions in science education?

The slowness of change in science teaching and learning cannot be blamed on a lack of knowledge about what works. Several major scientific, education, and business groups, as well as researchers and government agencies, have been working for several years on ways to improve science teaching and learning. There is a remarkable degree of consensus among these groups about what the problem is and how to resolve it. Many school districts have already put in place these promising new approaches and can document their success.

Some important shared beliefs underlying reforms in science education are:

- All students — not just a talented few — need an in-depth understanding of science; all students have the ability to achieve this understanding if they are taught in ways that encourage and build upon their natural curiosity and other abilities.
- Children learn more readily and remember things longer when they can connect new experiences and information with what they already know about the world — in other words, when they can actively construct their own knowledge.
- Young people build critical thinking skills and scientific habits of mind when they are allowed to become scientists — rather than simply studying science — by modeling the processes of inquiry and exploration that real-life scientists use to discover new knowledge.
- Students gain a more coherent understanding of major science concepts — the "big ideas"— when they revisit these concepts with increasing sophistication at various grade levels.

*There is a remarkable degree of consensus ...about what the problem is and how to resolve it.*

What does a classroom organized around these beliefs look like? Here, too, experts agree that certain instructional techniques are especially effective. Some promising characteristics include:

**Active learning.** Students *do* science, with ample opportunities to design and conduct experiments, to identify and solve problems, to participate in hands-on activities, to ask questions, and to discuss and reflect on their findings.

12

**Depth of content.** Teachers and students cover less material in greater depth, with an emphasis on related ideas and themes, rather than on terminology and facts.

**Varied groupings.** Classes include a mixture of instructional groupings, with provision for both group studies and independent work.

**Real-world connections.** Students connect science concepts with the natural world and explore how science and technology affect their lives and their society.

**Prior learning.** Instruction links new information clearly and logically with what students already have learned inside and outside school.

**Interdisciplinary approach.** Instruction stresses links among different scientific disciplines and, where appropriate, integrates science content with other subjects.

***Students connect science concepts with the natural world and explore how science and technology affect their lives and their society.***

# What are the implications of these new directions for educational policy?

Several major scientific, education, research, and business associations, organizations, and agencies have called for a redesign of science education. They include the American Association for the Advancement of Science, the National Science Teachers Association, the National Science Board of the National Science Foundation, the National Academy of Sciences, the National Center for Improving Science Education, the Triangle Coalition for Science and Technology Education, and many others.

A common theme underlying the work of these groups is that fundamental change is unlikely to occur unless reform is *systemic*. Moreover, these groups stress, the changes adopted must be compatible and must proceed in tandem.

In an educational context, systemic reform means several things. First, reform must address all students, particularly those populations now turning away from science. Second, reform must encompass all components of the educational system: curriculum, instruction, school organization, materials, testing and assessment, teacher preparation and upgrading, and policy development. It would do little good, for example, to initiate a hands-on approach to instruction and then use the same textbooks and tests.

***...fundamental change is unlikely to occur unless reform is systemic.***

Third, reform must be understood and supported by people from all segments of the community: teachers, administrators, school board members, students, scientists, college presidents, parents, researchers, politicians, business people, community leaders, and the general public. School policies do not arise in a vacuum; to some extent they reflect the values and demands of the larger community. To sustain the momentum for change for the ten years or more it is estimated to take, a broad public outreach and education effort is needed. Community people must be brought into the loop from day one and must believe that the proposed reforms are in their best economic and educational interest.

Fourth, reform must cascade through all levels of government: federal, state, and local. Federal mandates and funding programs exert a powerful influence on local practices. The role of state goals, requirements, and curricular frameworks, always a major shaping force, has grown in significance with the overall educational reform movement of the past decade. Local initiatives also need an appropriate policy context. It would make little sense, for instance, for a school to adopt a multidisciplinary curriculum if state graduation requirements remain segregated by discipline or if state universities refuse to accept this type of credit.

Signs on the horizon indicate that systemic reform of science teaching and learning is becoming a more achievable goal. Professional organizations are working with the National Research Council to develop voluntary, national standards for science curriculum, instruction, and assessment. If the standards that emerge garner broad support, they might serve as a banner behind which reforms in classroom practices, testing, and staff development could proceed.

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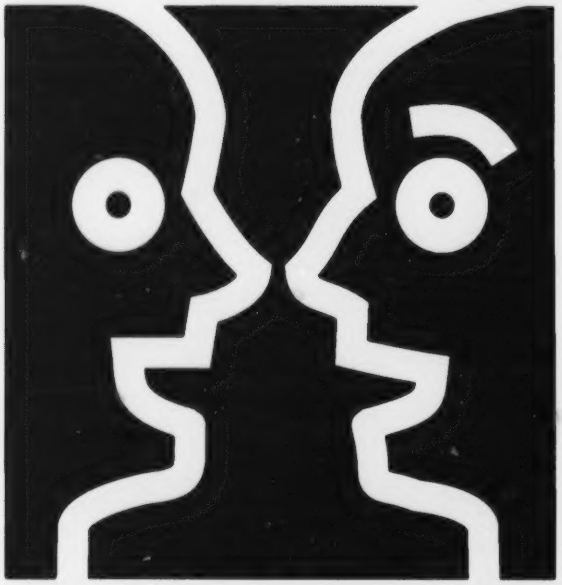

# Science in the Classroom

# *Why is science a unique, valuable, and potentially exciting area of education?*

Science is more than a body of knowledge; it is a way of looking at the world and ordering one's experience. The study of science presents an incomparable opportunity to open young minds to new vistas and to equip them with intellectual tools that will guide learners for the rest of their lives. That traditional science instruction passes up this opportunity is one of its more regrettable features, say many researchers.

Research suggests that science education is most effective when it captures the beliefs and "habits of mind" — or methods of thinking — that guide scientists in their own explorations of the world. What are these beliefs and methods? Among them are the beliefs that the world is understandable; that ideas are not fixed but grow and change over time; that scientific knowledge is durable; and that science cannot explain all things. Science also values certain rational methods of inquiry. These include careful observation, thoughtful analysis, healthy skepticism, the blending of logic and imagination, and the development of sound and coherent predictions and explanations.

***In the effective science classroom, the activity of finding out is as important as knowing the answer.***

In keeping with these beliefs and methods, good science teaching encourages students to be curious, creative, open-minded, skeptical, willing to suspend initial judgments, able to collaborate with others, and persistent in the face of failure. Research has validated several teaching strategies for developing these qualities and thinking processes. In the effective science classroom, the activity of finding out is as important as knowing the answer. For example, teachers might begin by posing questions about nature: What causes hurricanes? Why do some children look like their parents?

To answer these questions, students go about the tasks of observing, collecting evidence, describing, and sorting. The next round of activity might involve asking more questions, following hunches, developing hypotheses, debating, and defending conclusions to other students. By continually moving back and forth among questions, observations, and experiments, students refine and validate their hypotheses, and at the same time hone their thinking skills. Another exciting approach is to create a classroom environment in which students themselves ask fundamental questions to be investigated.

# *What should students know and be able to do in science?*

Most researchers, scientists, and science educators agree that students must not only know a body of information about science, they must also be able to do a range of scientific tasks and processes. The difficult job still remains of forging a consensus about precisely *what* students should know and be able to do.

Several professional science and education organizations have developed their own preliminary guidelines that address this issue. A number of them have come together with the National Research Council of the National Academy of Sciences to develop voluntary, national standards — using a critique and consensus process — for what students at different grades should know and be able to do in science. The umbrella group overseeing this project is known as the National Committee on Science Education Standards and Assessment. It is an outgrowth of the national education goals developed in 1989 by former President Bush and the nation's governors at their Charlottesville, Virginia, education summit. In addition to producing standards, the Committee has been charged with developing criteria for teaching and assessing progress toward these standards.

> ***A number of [organizations] have come together with the National Research Council of the National Academy of Sciences to develop voluntary, national standards — using a critique and consensus process — for what students at different grades should know and be able to do in science.***

The Committee does not expect to release a complete set of standards until 1994. However, some broad, common themes about what students should know and be able to do have emerged from the independent work of various professional organizations. Among them are that all students should:

- Be able to use inquiry and other scientific thinking skills, such as observation, measurement, and inference.
- Understand certain fundamental concepts that cut across scientific disciplines, such as change, systems, and stability.
- Have a solid grasp of the most important content in the traditional scientific disciplines (no matter whether this content is learned through an integrated or a disciplinary approach). Examples might include the human life cycle, the structure of the universe, and the composition of the atmosphere.
- Know how scientific ideas and discoveries have evolved and matured through history.

- Understand the distinction between science and technology and the role of technology in shaping the environment and human society.

- Be able to apply science knowledge and processes to weigh social issues, solve real problems, and make decisions.

The efforts to establish standards assume that knowledge and capabilities will become deeper and more sophisticated as students proceed through school. Part of the process of developing standards is to identify benchmarks that build upon one another for what students should know and be able to do at different grade levels. For example, the American Association for the Advancement of Science (AAAS) has undertaken Project 2061, a long-term initiative to reform science, mathematics, and technology education in the U.S. As part of Project 2061, AAAS has drafted the following preliminary benchmarks in the area of heredity and evolution:

***The efforts to establish standards assume that knowledge and capabilities will become deeper and more sophisticated as students proceed through school.***

- By the end of grade two, students will know that different kinds of plants and animals live in different environments and have characteristics suited to their particular environment.

- By the end of grade five, students will know that some characteristics of individuals are inherited.

- By the end of grade eight, students will know that differences in characteristics allow some individuals to be more successful at reproducing than others.

- By the end of grade twelve, students will know that differing survival values of inherited characteristics can explain how populations of organisms change over time.

The benchmarks and standards that emerge from all of the aforementioned projects will help educators redesign curricula and thematic units so that they are sure to cover the most important science skills and knowledge.

# When should science instruction begin and how long should it continue?

Every student should study a meaningful amount of science every year, beginning in kindergarten — or even earlier — and continuing until high school graduation. That is the consensus emerging from major studies of science education.

Reality, however, is far from this ideal. In most elementary schools, science receives considerably less attention than reading, writing, and mathematics. In kindergarten through grade three, less than 20 minutes daily is spent on science, on average; in the upper elementary grades, the average is about half an hour. The underlying message is that science is not all that important.

***Research has found a positive relationship between the amount of science instruction students receive in elementary school and their participation and achievement in science courses in secondary school.***

Research has found a positive relationship between the amount of science instruction students receive in elementary school and their participation and achievement in science courses in secondary school. Building on this notion, most people who have studied the issue strongly recommend that science be treated as a genuine "basic" in the elementary school curriculum and thereafter. Some groups have proposed specific amounts of time for science at different levels of schooling.

It is not just a question of the amount of science, but also of the quality of instruction. While the presence of active, high-quality science education in the formative years will not ensure that all students become scientifically literate, experience suggests that its absence is even less likely to fulfill this goal. Good science teaching and learning in elementary schools does not require expensive and complicated equipment — just a teacher with the imagination to design simple and concrete experiments that will "hook" children in the active pursuit of scientific knowledge.

At the middle school level, students need instruction that links the concrete learning they acquired in elementary school with the more abstract concepts and critical thinking demands of high school science. They also benefit from instruction that emphasizes the personal, career, and social uses of science; builds on their growing need for independence; and takes into account special concerns of adolescents, such as human development.

At the high school level, it is critical that all students receive quality science courses. Particular attention should be paid to students who have been underrepresented in science, including girls, ethnic minority students, and students pursuing vocational studies. Regardless of gender, demographic or social group, or career aspirations, all students will be better prepared for the future as a result of the thinking skills and habits of mind that the study of science builds.

A final note: science learning does not end with formal schooling. The need for scientific literacy among all citizens suggests that the nation should embrace the concept of lifelong learning in science. However, while many education options exist for adults who need to upgrade specific technical and job-related skills, there are far fewer opportunities for those who wish to gain a deeper understanding of science.

***The need for scientific literacy among all citizens suggests that the nation should embrace the concept of lifelong learning in science.***

# What is the right balance among traditional science disciplines?

> *...the best way to teach this knowledge is to expose students to rich content from the major disciplines every year...*

Most of us are familiar with the traditional "layer-cake" model of high school science that separates the major disciplines into year-long courses: earth and space science in ninth grade, biology in tenth, chemistry in eleventh, and physics in twelfth (for those who persist). In a conventionally organized school, this model — which, incidentally, differs from how science is taught in many European and Asian countries — appears to have certain advantages. It divides science into clear-cut, manageable blocks of time that fit the traditional high school schedule. It parallels the way high school teachers are prepared and certified. And it seems to offer students interested in science careers the chance to discover which subject best suits their talents and preferences.

Yet researchers who have taken a hard, objective look at the layer-cake model have concluded that, whatever its convenience, it has several drawbacks and may actually be detrimental to student learning. First, it fragments student understanding into disconnected bits and hinders students from making important thematic connections across and within disciplines. Second, it ignores the nature of the scientific *process*, which applies to all disciplines and which all scientists understand and use. Third, it allows most young people — particularly the 55 percent who exit the science pipeline before taking chemistry or physics — to graduate without a depth of understanding in any field. Some schools also offer general science courses for students in vocational or "general" tracks; far from solving the problems of the layer-cake model, these courses are often so watered-down as to give students only minimal content or experience in any of the disciplines.

Recognizing these problems, educators and scientists, with support from research, have developed new models for secondary school science curricula that integrate knowledge from several disciplines and seek to build problem-solving strategies that cut across traditional boundaries. Make no mistake: these reformers are *not* suggesting that students do not need a common core of knowledge from all the traditional scientific disciplines. To the contrary, they argue that the best way to teach this knowledge is to expose students to rich content from the major disciplines every year, in different contexts that highlight interrelationships and expose students to new issues, such as technology, seldom addressed by traditional courses.

How can this be accomplished in a practical way, especially when the length of the school day remains unchanged in most districts? Many researchers propose laying the groundwork in the elementary years by increasing students' exposure to integrated content with concrete connections to the real world. This might be followed in every year of middle school by courses that group content from different disciplines around major themes that students would study in greater depth and if possible during a longer period of time. For example, a teacher might organize a three-month unit on primates that incorporates such activities as mapping and modeling the fossil-rich Great Rift Valley (geology and anthropology); studying human and ape skeletons at a museum (zoology); and observing monkey behavior at a zoo (sociology, psychology, and environmental science).

***Some high schools are moving toward an interdisciplinary program that eliminates traditional subject boundaries and organizes content from all disciplines around major themes.***

Expert panels of scientists and educators have produced several stimulating models to improve coordination among science disciplines. These range from fully integrated approaches to disciplinary-based ones in which boundaries are softened and connections emphasized. Some high schools are moving toward an interdisciplinary program that eliminates traditional subject boundaries and organizes content from all disciplines around major themes.

Another model for high school science, proposed by the National Center for Improving Science Education, includes two years of core science for all students, including such half-year courses as case studies in the history and philosophy of science, and contemporary ecological concerns. After two years of core science, students may choose alternate pathways, depending on whether they plan to go to college, pursue postsecondary technical education, or enter the workforce. One pathway might include half-year introductory courses in each of the major disciplines; another might include year-long advanced placement courses.

Other models maintain discipline-based courses but attempt to foster better coordination through frequent teacher interaction and interrelated activities. One model developed under the Scope, Sequence, and Coordination (SS&C) project of the National Science Teachers Association proposes that students take four specialized courses each year, with one or two periods each week in every discipline. Another SS&C option proposes separate, short-term courses, with students taking a quarter-year course in each discipline each year.

Many other good models exist; the reasons they are not implemented more widely are often logistical. Schools are often reluctant to institute the types of flexible scheduling that redesigned courses require, and many lack the resources for necessary staff development. Parents are sometimes suspicious of unfamiliar curriculum structures. They need to understand that if their children are taking courses called science 1, 2,3 and 4, the children are still learning principles of biology and chemistry — in fact, probably learning them in greater depth. Another issue is that the mechanisms are not in place to effectively replicate and disseminate interdisciplinary models. Still another problem is that classroom resources — textbooks in particular — are not organized in ways that facilitate interdisciplinary instruction. But with public support for better science teaching and learning, these obstacles can be overcome.

***Another...option proposes separate, short-term courses, with students taking a quarter-year course of each discipline each year.***

# How do students' attitudes and perceptions about science affect science learning?

Attitudes and perceptions about science are powerful motivators working for or against student achievement. According to research, students who enjoy science are more apt to do well and take advanced courses. Similarly, students who dislike or fear science and doubt their own competencies are more likely to do poorly and boycott science altogether by late high school.

Negative attitudes about science are learned, not inherited. Any parent can describe the delight little children take in observing the world around them and experimenting with its limits. Yet somewhere in the elementary grades, these positive attitudes wither or find outlets apart from the subject in school called "science." By the end of third grade, almost half the students in one survey said they would not like to take science, and by the end of eighth grade, only one-fifth had positive attitudes toward science. Enthusiasm about science — and with it confidence — tends to dwindle as students progress through school.

***Negative attitudes about science are learned, not inherited.***

Several incorrect or damaging perceptions can fuel negative attitudes about science. One is that success in science stems from innate ability more than from effort, and that some students are just not cut out for this "hard" subject. This attitude is particularly pernicious for girls and minority students. Another is that scientists — and top science students — are eccentrics or "nerds." Some students show indifference to science to keep their status with peers who do not view science achievement as "cool."

How do attitudes and perceptions about science take root? Often they grow out of explicit or subliminal messages students pick up in and out of school, from teachers, peers, parents, books, the media, and authority figures. Students can sense if teachers or parents themselves are insecure with science. Sometimes parents or teachers developed negative attitudes about science when they were young because they were taught by traditional methods that dampened their interest.

The methods by which science is taught in most schools continue to affect student attitudes today. In one survey, 21 percent of students cited teachers as a reason they liked science; on the flip side, one-third cited instructional factors — such as too much lecturing — as reasons they disliked science. When science is taught as a tedious inventory of facts and theories, it is no wonder students begin to perceive science as dull and complicated.

In addition, instruction that overemphasizes competition can produce early experiences with failure, which in turn can breed a dislike for science and a lack of confidence about future success. Similarly, teachers may subtly transmit their expectations about what students can and cannot do so that students internalize them.

Negative attitudes can have long-term consequences, such as students foreclosing their options in a subject they believe they have little hope of mastering anyway. The good news is that attitudes can be changed through teacher and parent modeling and through more engaging instruction.

***The good news is that attitudes can be changed through teacher and parent modeling of positive attitudes and through more engaging instruction.***

# How can teachers motivate students to enjoy and want to learn science?

Consider this tale of two classrooms. Ms. Judge's eighth-grade science class is listening — a charitable term given the noise level — to a lecture about photosynthesis. Textbooks lie open. On the blackboard is a drawing — a rather adept one in colored chalk — of a plant, the sun, and the soil, with arrows connecting them. In the middle of Ms. Judge's explanation of the roles of carbon dioxide and water, Nick, a bright student who only occasionally achieves at his potential, asks, "Is this going to be on the test?" When Ms. Judge answers yes, the conversational buzz subsides and note-taking increases, but the teacher wonders whether any of her students really care.

Down the hall, Ms. Gioia holds up a potted green plant and poses the question: how do plants come by their food? "They make it themselves," says Crystal, and most of the other students nod. Although someone interjects the term "photosynthesis," Ms. Gioia realizes through follow-up questions that no one really knows what this concept means, or what plant food is. She then challenges the class to help her design an experiment that would clarify the issue. Students congregate in small groups, debating how to structure an experiment. One group comes up with the idea of looking at the variety of plants they have in the classroom. Another group suggests looking at the variables that are likely to influence plant growth. In the next class, students begin an experiment that examines the amount of light that different plants need, which they will eventually graph and expand to include other variables.

*One effective approach is to make lessons relevant to students' everyday lives.*

As these vignettes show, teachers can use a variety of approaches to kindle students' interest in learning science. One effective approach is to make lessons relevant to students' everyday lives. Though "relevance" became something of an overused catchword in the 1960s, it need not imply a lack of rigor. In the contemporary science classroom, relevance refers to instruction that focuses on meaningful, real-world topics — in health, energy, or the environment, for example — that students care about and perceive as useful to themselves and society. Similarly, teachers can motivate students by asking them to solve non-trivial problems that yield an intellectually satisfying payoff.

An important lesson from research is that students are more motivated when teachers hold them to high expectations. Teachers and schools can signal high expectations in a variety of ways: by setting up challenging but attainable tasks; by giving praise effectively when it is deserved; by using success in one activity to build upon another; and by establishing rewards for student effort.

The positive effects of scientific inquiry processes on student motivation should not be overlooked, either. When students explore, solve problems, and conduct experiments, they gain a sense of ownership over their own learning that can spur them to take risks they would be unlikely to take in a classroom that rewards only correct answers and textbook problems. In keeping with the scientific method, students should also be given opportunities to generate or choose their own questions, problems, and experiments.

***In one class, reorganized around an active approach, 87 percent of students reported liking science, compared to 38 percent before.***

Another theme that runs through the research literature is the importance of active, hands-on learning as a motivating factor. In one class, reorganized around an active approach, 87 percent of students reported liking science, compared to 38 percent before. It should be noted that young children are not the only ones to flourish in active learning; adolescents also have great reserves of physical energy to channel into productive hands-on outlets.

Appealing to aesthetic sensibilities is a powerful but sometimes overlooked way to motivate young people. The beauty of a geode, a whale's song, or a suspension bridge can captivate the imaginations of both children and adolescents and evoke reflections about the relationships among the scientific, the aesthetic, and even the spiritual realms.

Finally, research shows that teachers can motivate students by modeling the qualities they want students to possess: wonder, persistence, and enthusiasm, to name a few. When a teacher expresses delight with the outcome of a student experiment, he or she does more to build confidence than do most test results.

# *How can schools reverse the signal that science is not a high priority?*

No school wants to have an ineffective science program. If asked, school administrators, board members, and teachers would likely agree that science is one of their top priorities. Yet schools sometimes send signals that subvert this message or adopt policies that make effective science instruction difficult to carry out.

The first problem is that science is not treated as a core subject in the same way that reading and math are. Science is given relatively little time in the school day, especially in the elementary and middle grades; nor is it mandated through all twelve grades.

Another problem is that many schools do not reward accomplishments in science to the same extent that they recognize success in other areas, including extracurricular activities and sports. The rewards that exist are often reserved for the few best students, which discourages others from even trying. Still another problem lies with inflexible policies on such matters as scheduling time for laboratory work or allowing classes to go on field trips.

Placing a low priority on science is not unique to elementary and secondary schools. One study found that, except for a few scientific and technically oriented universities, admission to most of the nations' selective colleges and universities is not influenced significantly by achievement in science and technology. Similarly, most major college admissions tests do not assess achievement in science.

***...many schools do not reward accomplishments in science to the same extent that they recognize success in other areas, including extracurricular activities and sports.***

Schools can turn this situation around through several means. Instituting school-based rewards for learning, establishing science clubs, holding science fairs, encouraging teachers who want to implement promising instructional practices, forming partnerships with businesses and communities, and reserving more time for science instruction are just a few possibilities.

None of this will happen, however, unless school leaders themselves believe that there is a need to improve science instruction. Higher education institutions also can play a role by reassessing how they use test scores and student transcripts. Communities and parents can help, too, by convincing schools, colleges, and universities of the need for change and by supporting reform efforts.

# What special problems do girls face in science? What can schools and teachers do?

Gender equity is a persistent challenge in science teaching and learning. A host of studies confirm that as girls progress through the educational system, their achievement and enrollment in science courses decline relative to that of boys. At age nine, girls and boys perform about the same on science assessments, except in the physical sciences. By age 13, an achievement gap materializes in most science content areas, and by age 17, girls achieve at a significantly lower level than boys, especially in physics. Girls as a group also have developed more negative attitudes about science. By age 11, boys show a more positive view of science on interest surveys than girls do.

Girls tend to drop out of the science pipeline earlier than boys. A fair share of girls take biology, but fewer girls — even highly talented ones — take chemistry or physics compared with boys. Of the students who take chemistry (an already limited segment of the school population), 34 percent are girls and 66 percent are boys; for physics the figures are 22 percent girls and 78 percent boys.

*Parent and societal attitudes, adult examples, and deep-seated myths about the respective proficiencies of girls and boys are just some of the factors that shape girls' attitudes about science.*

The winnowing that occurs in high school means that fewer females than males are adequately prepared for college science or for scientific and technical careers. Labor market statistics bear this out. In 1986, only 13 percent of employed scientists, mathematicians, and engineers were women, although women made up 49 percent of all professional workers. This underrepresentation of females in science represents a serious drain on the talent pool for critical scientific and technical jobs.

Several studies have probed the reasons behind these patterns and have concluded that girls receive differential treatment when it comes to science. The roots of the problem begin well before formal schooling. Parent and societal attitudes, adult examples, and deep-seated myths about the respective proficiencies of girls and boys are just some of the factors that shape girls' attitudes about science. The toys they play with, the tools they use, the storybooks they read, the types of encouragement they receive — all affect girls' perceptions about and familiarity with science.

Once girls enter school, their experiences are further influenced by classroom patterns, sex stereotyping, and even overt discrimination. Girls receive less encouragement than boys from teachers, counselors, and other school personnel. Teachers have higher expectations in science for boys and are more likely to call on boys than girls to answer complicated questions. Teachers also show girls less attention and give them less feedback. One study found that 79 percent of student-assisted science demonstrations were carried out by boys.

Sometimes science classes create environments that are more comfortable for boys than for girls. For example, girls may be less familiar than boys with certain equipment or techniques, such as connecting a car battery. According to one study, in lab situations boys tended to take control of equipment, with girls often relegated to the complacent role of notetaker.

*Fortunately, recent research is replete with recommendations for classroom activities that empower girls in science.*

Texts, materials, and media reinforce messages that science is a male domain. Girls need only take note of the shortage of female role models among high school science teachers and department heads, scientists who volunteer in schools, and women in technological and science careers.

Experiences outside school during the critical elementary and secondary years augment messages that girls receive in school, with the result that females report fewer science-related activities outside of school. Beyond high school, girls are forced early on to begin considering decisions about career versus family.

The critical question, of course, is what schools and teachers can do to reverse this situation. Fortunately, recent research is replete with recommendations for classroom activities that empower girls in science. Among them are the following:

- Hold all girls to high expectations for performance and course-taking and provide them with active counseling and encouragement to counteract stereotypical messages.

- Use an abundance of hands-on activities to counteract girls' lack of familiarity with physical science. Enlist girls' help in demonstrations and experiments.

- Structure science activities so that girls play active rather than passive roles; take special steps to ensure that boys do not dominate lessons.

- Encourage guessing, questioning, and exploration to reduce girls' anxiety and build their confidence about science.
- Provide plenty of opportunities for cooperative learning, which can improve instruction for both girls and boys.
- Showcase female role models and career options by bringing in guest scientists, disseminating career information, and creating bulletin boards about women in science.
- Use gender-fair books and materials.
- Educate teachers and other school staff to become aware of subtle behaviors that discourage girls or communicate low expectations.

***Encourage guessing, questioning, and exploration to reduce girls' anxiety and build their confidence about science.***

# *What special problems do minority students face in science? What can teachers and schools do?*

The demographics are clear. By the year 2000, minorities will constitute roughly 30 percent of American students. By 2020, if present trends continue, this proportion will increase to well over 50 percent. The full participation of minority students in science is absolutely critical to the nation's economic and social prosperity. More important, an understanding of science is a crucial step towards personal satisfaction, intellectual challenge, job preparation, and citizenship for minority young people, as for all young people.

While efforts have been made to encourage all students to participate fully in science, African-American and Hispanic students still perform below their white peers in science and are severely underrepresented in science course enrollments. Even with recent gains, the average proficiency of 13- and 17-year old African-American and Hispanic students remains significantly behind that of white students. Only a small fraction of African-American and Hispanic students takes chemistry and physics. Mirroring these trends, African Americans and Hispanics each made up only two percent of the scientific workforce in 1986. Though less data are available for Native Americans, they share similar problems of achievement and underrepresentation.

The reasons for these disheartening trends are deep-rooted, beginning with a history of discrimination, including restrictions on both employment and educational opportunities for minorities. Discrimination, stereotyping, and differential opportunities persist today in schools and in society. Many of the problems begin before children enter school. Because many minority children come from low-income families and neighborhoods and have parents with low levels of educational attainment, they often lack early science opportunities that their more advantaged peers take for granted: reading books in the home, taking trips to museums and zoos, or even noting a plant's growth.

As a result of these disparities, a great number of minority children are behind in science from the day they enter school. As they progress through the grades, minority children routinely receive less challenging science instruction, less interaction with teachers, and more restricted learning activities. It is also not uncommon, according to research, for teachers to hold lower expectations for minority students. This situation is particularly acute for minority girls.

***As a result of these disparities, a great number of minority children are behind in science from the day they enter school.***

Discrepancies of opportunity exist not only at the individual level, but also at the school level. Schools in which minority students comprise a majority tend to have high proportions of low-income children, fewer resources, inferior facilities and equipment, less qualified teachers, and fewer advanced course offerings.

Improving science opportunities for minority students and strengthening science programs in the schools they attend rank among the highest priorities of the major groups advocating science education reform. Researchers who have studied effective practices for accomplishing these goals have reached several common conclusions, as well as some conflicting ones. Among the most significant findings (as well as areas of debate) are the following:

- Schools should make greater efforts to avoid grouping or tracking practices that serve a gatekeeping function for minority children. Some researchers recommend eliminating grouping entirely because of its pernicious effects on minority students.
- Effective science programs should incorporate course content and activities that are relevant to minority students' daily lives and out-of-school experiences.
- Teachers should show appreciation for diverse cultures and sensitivity to language variables and cultural norms. (An example would be to avoid the use of animal specimen remains in teaching science to Native-American children.)
- Some researchers argue that minority children may have identifiable learning styles — such as a preference for group learning and varied tasks — and that instruction should be adjusted accordingly. Others do not find this evidence persuasive and advise focusing energies on instructional approaches that are shown to be effective for all children.
- Minority students should have access to challenging, activity-based, hands-on instruction.

***Improving science opportunities for minority students and strengthening science programs in the schools they attend rank among the highest priorities of the major groups advocating science education reform.***

- Schools should make efforts to highlight the contributions of minority scientists and should provide opportunities for students to interact with role models, including minority men and women in scientific careers and successful college science students.

- Teachers, counselors, and other school professionals should hold high expectations for minority children and provide them with ample opportunities for success.

- Schools should provide counseling to encourage minority students to participate in challenging science courses and to make them aware of opportunities for higher education and employment.

- Schools should organize training for teachers and other staff to ensure that they are sensitive to minority children's cultures and special needs.

- Federal, state, and local governments should ensure that schools with high enrollments of minority children receive their fair share of resources.

***Schools should make efforts to highlight the contributions of minority scientists…***

# What special problems do LEP students face in science? What can teachers and schools do?

*...the LEP student may be placed in a science class in which no one, including the teacher, understands his or her native language.*

Limited-English-proficient (LEP) students face a range of challenges in learning science. The most obvious one is having to learn a new language at the same time they must master demanding new subject matter. Depending on the school's resources for language instruction, the LEP student may be placed in a science class in which no one, including the teacher, understands his or her native language.

Many LEP children are recent immigrants who received little or no formal schooling in their homelands and must cope with the additional, daunting tasks of adapting to a new culture and an unfamiliar educational system. Others are U.S. citizens whose culture differs from that of the school or who may have had scant exposure to science in the home.

The nature of science presents additional obstacles. Science has a unique vocabulary, with terms that an LEP child is unlikely to encounter in other contexts or in English as a Second Language instruction. A typical science course introduces as many new vocabulary words as a typical foreign language course. Although the sequences in which children learn are intricate and unpredictable, researchers know that for students to master key scientific concepts they must at some point advance into "abstract" thought. LEP children sometimes experience difficulties moving to higher levels of abstraction without the support of language connections. As a result of these obstacles, many LEP students never catch up to their English-speaking classmates in science achievement.

Some forward-looking school districts are implementing research-based programs to close these students' gap in science achievement. One such program, the California Academic Partnership Program, helps students discern some source of "cultural reference" in learning science. Near-peer undergraduates, who were initially LEP students themselves, serve as tutors — bilingual bridges — who explain scientific concepts to students. Other strategies in this partnership emphasize parental and community involvement. Newsletters, in-home visits by teachers and university faculty, and field trips to local universities and businesses underscore the relationship between LEP achievement in science and future careers paths.

Research appears to support, where possible, a bilingual approach to LEP students' special needs. When bilingual teachers and aides are not available, a monolingual science teacher can still show sensitivity by systemically incorporating linguistic objectives into science activities, taking care to explain unfamiliar terms in more everyday English, and using culturally relevant problems and tasks.

Several successful "intervention" programs for LEP students emphasize the social aspects of learning, often through heterogenous cooperative groups. Teachers need to be aware, however, that the same type of teaching and learning does not work for all the cultural groups that comprise the LEP population. Some students may not learn well in cooperative learning groups and instruction should be modified accordingly.

Hands-on activities and demonstrations are a good way of illuminating science concepts for the LEP child, along with activity-based and practice-oriented instruction. Researchers note the importance of integrating language development with science learning. Hands-on science activities are ideally suited to language development, especially when pursued in teams and when teachers encourage questioning and verbal explanations for solutions. These integrated approaches, which are particularly effective in the early elementary grades, serve both language and science learning needs.

***Researchers note the importance of integrating language development with science learning.***

Perhaps the best way to help LEP children, however, is for teachers, administrators, the public, and the scientific community to begin to view language minority children as an asset in the science classroom. These children can provide language enrichment for native English-speaking children and ample opportunities for interesting cross-cultural instruction.

# What problems do children with disabilities face in science? What can teachers and schools do?

Although some of the most ground-breaking accomplishments in science have been made by persons with disabilities, as a group these individuals are among the most underrepresented in scientific and technical fields. Disabled men and women comprise only .0004 percent of scientists and engineers — a shockingly low percentage in light of the fact that nine percent of the population is disabled.

Students with disabilities — whether physical mobility, hearing, or visual impairment — are able to participate fully and comfortably in science programs if they are provided with appropriate instruction and access. To every extent possible, children with disabilities should be served in regular science classrooms. There are several effective ways to ensure access and tailor instruction to the special needs of these students.

In general, research has found an active, multi-sensory approach — including hands-on science and scientific inquiry — to be effective for children with disabilities, as it is with any other child. As one study concluded, the science teacher who uses reading and writing as the sole means of instruction will give all of his or her children a handicap. Children with disabilities may need to carry out their explorations differently, however.

***Students with disabilities...are able to participate fully and comfortably in science programs if they are provided with appropriate instruction and access.***

As with any component of a disabled child's educational program, an individualized approach tailored to the student's needs is advisable. For instance, larger hands-on materials may help the child with limited fine motor skills. A child with a physical handicap may require a lightweight table top to place over the wheelchair arms. Teachers need to take special care to design experiments and demonstrations that do not isolate disabled students. Cooperative learning that groups disabled students with other students is often an effective technique. For example, audiotaping instructional materials for a visually impaired child could become an ongoing *class* project, in which sighted children take turns and increase their own learning in the process. Children with disabilities, in turn, might use their unique talents to help their classmates. Through cooperative learning, a child with disabilities will learn science at the same time his or her peers gain important knowledge and attitudes about students who seem different.

Educational technology that is adaptable for use by disabled students is another option for expanding learning opportunities.

An increasingly sophisticated array of adaptive devices is becoming available for physically challenged children. And technologies that benefit all children, such as electronic networks, provide new opportunities for communication and learning for disabled children.

Research has also examined specific means for addressing different types of disabilities. Among them are the following:

- Activities that use touch and motion are particularly effective for visually-impaired and hearing-impaired students. Auditory or visual learning, whichever is appropriate, should also be part of instruction. For example, one report suggests asking students with visual impairments to note what they hear during field trips.

- For students with mobility impairments, schools must be sensitive to accessibility, particularly in planning field trips or conducting experiments. Schools may need to make some minor modifications to the classroom itself, such as rearranging seating and assigning work spaces.

- Science activities can be particularly therapeutic for emotionally disturbed children. By allowing them to manipulate and control variables, science can provide a unique opportunity for these children to operate in responsible ways and gain self-confidence.

***An increasingly sophisticated array of adaptive devices is becoming available for physically challenged children.***

# What kinds of activities and projects promote active learning?

When our great-grandparents were children a century ago, most of them acquired a wealth of science knowledge outside school just in the ordinary course of their lives: figuring out how much wood to bring in to heat the house, caring for livestock, and growing and preserving food. Most children today do not have such chores; as conveniences have increased, opportunities to learn about the world in an active and natural way have diminished.

Active, open-ended exploration in the early years plays a crucial role in a child's intellectual development. Building on this conclusion from cognitive research, evaluators of classroom practice have uncovered positive associations between active science instruction (sometimes called participatory learning) and student achievement, attitudes, and interest.

***Usually active learning is part of a broader strategy to build students' self-direction using the processes of inquiry, exploration, and experimentation that scientists employ in the real world.***

Although there is no guarantee that active learning alone will raise achievement, the collective benefits of this approach are sufficient to prompt many researchers and practitioners to endorse it as the backbone of elementary science instruction and an important component at all grades. The science curriculum framework for the state of California, for instance, stipulates that 40 percent of class time should involve hands-on activities.

Active learning is based on the belief that students learn best when they construct their own understandings by interacting with the natural world, each other, and their teachers. Usually active learning is part of a broader strategy to build students' self-direction using the processes of inquiry, exploration, and experimentation that scientists employ in the real world. On a practical level, active learning encompasses an enormous variety of activities: students manipulate "hands-on" objects, collect and catalogue specimens, organize data, observe and record animal behavior, interview people, plant and cultivate flora, focus a microscope, measure rainfall, graph changes in their own height — the list goes on. Active learning need not be restricted to the classroom or the laboratory. It lends itself well to field trips and other community learning experiences.

Despite the favorable evidence, many schools have been slow to adopt active learning. Studies show that lecturing and discussion are far and away the dominant mode of science instruction, comprising 75 percent of teaching time in kindergarten through third grade and nearly 90 percent in upper elementary grades.

Similarly, an International Assessment of Educational Progress study conducted in 1988 found that among 13-year-olds, only 28 percent of American students reported doing experiments with other students or by themselves with high frequency.

Even when schools report using experiments or demonstrations in their science programs, this does not necessarily mean that students are being actively engaged. At the high school level, laboratory experiments too often are conducted in a procedural way — like following recipes in a cookbook — that minimizes student engagement and leads to a predetermined conclusion. And in the lower grades, the teacher frequently conducts demonstrations, perhaps with the help of a few selected children, while other students sit and watch. Moreover, even hands-on instruction in which all children participate is not automatically "minds-on" instruction. For the activity to be effective, teachers must link it with specific science concepts and allow ample time for analysis, interpretation, and classroom discussion.

Teachers and principals cite several reasons for why they are reluctant to implement active instruction. Many of these reasons are logistical: lack of special materials and equipment; insufficient time to organize and set up experiments and investigations; concerns about efficiency and discipline; and insufficient staff development for teachers. Researchers counter that participatory learning can be realized for only a modest additional cost. Besides, they argue, the organizational obstacles that impede active learning are the same ones that perpetuate ineffective science teaching and learning and should be changed in any event.

***For the activity to be effective, teachers must link it with specific science concepts and allow ample time for analysis, interpretation, and classroom discussion.***

# *What instructional methods support scientific thinking and problem solving?*

U.S. education is often criticized for paying too little attention to complex thinking and reasoning skills — the "higher-order" skills — that students need to become lifelong learners and flexible workers. According to the National Assessment of Educational Progress, performance gains in the 1980s occurred primarily in basic facts and low-level skills. Few students showed proficiency in complex reasoning and other higher-order skills.

Problem solving resists a simple definition. Experts suggest that problem solving be viewed as a continuum. At one end are exercises with solutions — such as how to balance items on a scale. At the other are problems to which no one has the answer, such as how to create conditions in which cold fusion will transpire. Problems typically assigned in science classrooms, such as blackboard demonstrations and end-of-chapter exercises, fall at the low end of the continuum.

***The type of problem solving recommended in research more closely parallels the processes and habits of mind that scientists use, including logical reasoning, questioning, analysis, and hypothesizing.***

The type of problem solving recommended in research more closely parallels the processes and habits of mind that scientists use, including logical reasoning, questioning, analysis, and hypothesizing. This form of problem solving helps students gain a deeper understanding than simply memorizing science facts. It can be a terrific motivator, especially if the problems address interesting, non-trivial, real world issues. And contrary to popular wisdom, it is appropriate for students of all ages.

One model from research asks teachers to guide students through four distinct stages of problem solving:

**Invitation**. A question from a student or the teacher invites students to learn more about concepts that intrigue them.

**Exploration, discovery, and creativity**. Students develop experiments and use other methods of inquiry, such as observation and revision, to begin to answer the initial question.

**Proposing explanations and solutions**. With support from the teacher, students develop, discuss, and debate explanations consistent with the results of their experiments.

**Taking action**. Students follow up on what they have learned through such means as writing a letter or initiating action in their homes or communities.

Another model for building problem-solving skills engages children in designing technological solutions to real-world challenges. Children engage in four phases of inquiry:

**Investigation**. A child poses a question, becomes aware of a need or problem, or accepts a challenge.

**Invention**. Students plan and design alternative ways to address the challenge.

**Implementation**. Students test and modify their original design.

**Evaluation**. Students evaluate both the product they developed and the process they used.

***Help students use the tactic of working backward from what they want to find out as they devise a plan.***

For example, in one classroom, second graders used half-gallon milk cartons to design a habitat for an animal they selected. The habitat had to include an offset wheel that would allow the animal to jump up and down. Students saw how important it was to measure accurately and to stabilize the wheel. They also researched the animal's movements. From this project, children synthesized design concepts, aesthetics, basic scientific principles, and language concepts.

Research contains other tips for teachers to make problem solving more effective. Among them are:

- Use intentionally open-ended questions.
- Help students see ways to keep track of their thinking steps as they solve problems.
- Encourage students to be active and use pencil and paper or other materials.
- Help students use the tactic of working backward from what they want to find out as they devise a plan.
- Use familiar procedures and equipment to introduce new problems.
- Encourage mobility and student interaction.

# How can cooperative learning and other classroom organizations promote science?

Stereotypes of the isolated genius aside, real life science is more often than not a collaborative venture. Reflecting this reality, many science teachers are moving toward a cooperative learning approach in which small groups of three or four students work together on a problem or experiment. These teachers have allies in many researchers who believe cooperative learning is an effective technique for improving science knowledge, building social and communication skills, and motivating students by reducing counterproductive forms of competition.

Cooperative learning encourages students to share responsibility for learning. Students develop approaches and explanations, exchange information, talk and listen, argue, and persuade. They learn to order their thoughts and compare their own thinking processes with those of their peers. Students also become involved in tutoring and in encouraging each other. When cooperative learning is implemented effectively, all students have a chance to be successful and everyone's effort contributes to the group results.

***Stereotypes of the isolated genius aside, real life science is more often than not a collaborative venture.***

Groups have the added advantage of being able to tackle more challenging assignments than students could do alone. In fact, some studies contend that there are certain science learning outcomes that can be assessed only in groups, such as integrating team findings into a final product.

The teacher plays an important facilitator role by forming the groups, observing and moderating, answering questions, encouraging the flow of ideas, and synthesizing findings. Teachers must take care to put together groups that best benefit the learner by addressing students' interests, abilities, and behaviors. In any case, teachers should avoid groupings that foster bias by achievement, gender, race and ethnicity, or handicap. Homogenous groups for cooperative learning are not usually recommended, especially at the elementary level. Groups should also be flexible and rearranged periodically.

Teachers should also take care to design an activity appropriate for group learning. Simply putting children together to do a task meant for one child is not cooperative learning.

Effective cooperative learning requires a spacious room with flexible seating. It also requires additional training because not all teachers know how to execute it.

Not all researchers are convinced of the benefits of cooperative learning. Some contend that in certain situations no student has expertise to contribute and, in others, group interactions can reinforce stereotypes or make some students feel like failures. A synthesis of research suggests that cooperative learning must be implemented with care and is not appropriate for every activity in the science classroom. Thus, the ideal science classroom uses a mix of full-class activities, large-group presentations, cooperative learning, and individual projects or independent study.

Some schools are also experimenting with other non-traditional classroom organizations for science teaching and learning. These include team teaching, extended block scheduling, and out-of-school trips.

***Thus, the ideal science classroom uses a mix of full-class activities, large-group presentations, cooperative learning, and individual projects or independent study.***

# What does research say about grouping children by achievement in science education?

Grouping by achievement levels — sometimes referred to as "ability" grouping — is a common practice in science, especially at the secondary school level. Achievement grouping may affect students at all learning levels and may take different forms. Placing children in an elementary remedial program is one form of grouping; selecting gifted students for a special high school science course is another.

Research notes several problems with existing grouping techniques, but it is divided on how best to overcome them and whether heterogenous groupings are desirable and workable in all situations.

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Achievement grouping often begins in elementary school. For example, students labelled as "disadvantaged" may be placed in remedial programs or separate learning groups for part of their instruction. Studies critical of this practice contend that the groupings often reflect students' home and family circumstances more than their ability, with minority and low-income children overrepresented in the lowest achievement groups. The low-group or remedial students frequently receive different, less-challenging content than their classmates, delivered through less-effective instructional modes, such as a drill of basic facts. As a consequence, they may miss out on some knowledge that their mainstreamed peers are learning and fall even farther behind.

At the middle school and junior high school levels, students are often tracked by achievement and interests. One survey found that about two-thirds of middle and junior high schools used some achievement grouping, and more than 20 percent organized all classes by achievement. Achievement grouping was also found to be more prevalent in schools with large African-American and Hispanic enrollments.

Further division occurs in high school, where students are often organized into college-prep, vocational, and general tracks. Several studies have found that because different values are placed on these alternatives, these common forms of achievement grouping negatively affect the academic performance, self-esteem, and future education and career options of the "lower" groups.

It is understandably difficult for teachers to organize material that addresses the needs of both honors students and low-achieving students. Moreover, schools face strong pressure from parents of advantaged or scientifically talented children to maintain some form of homogenous grouping.

Some reform reports recommend eliminating tracking altogether and providing all students with a common, radically redesigned curriculum. In a rich and active curriculum, they argue, heterogenous groups will succeed because both higher-achievement and lower-achievement students will be actively engaged. Proponents of this model cite studies where students at all educational levels in heterogenous classes performed well at the end of the year compared to tracked classes. Remedial students had the largest overall gains, but average students also improved and accelerated students still did slightly better in a mixed setting.

***Finally, researchers make the point that when schools make other organizational and pedagogical changes, the issue of achievement grouping becomes less significant.***

Other studies advocate a combination approach at the high school level, in which students study a common core of science in socially heterogenous groups for the first years, then diversify in the later years. Upon completing the common core, students would be loosely grouped according to whether they intended to pursue college, postsecondary vocational education, or workforce preparation, with ample chances to switch. Most important, the content in each of these pathways would cover the key concepts from all major disciplines in a rigorous way.

Finally, researchers make the point that when schools make other organizational and pedagogical changes, the issue of achievement grouping becomes less significant. By using a range of active and exploratory approaches — such as nongraded classes, team teaching, and concept-based instruction — plus a combination of large groups, small groups, and individual study, all students will receive quality instruction.

# What roles do questioning, discussion, and reflection play in learning science?

As Socrates well understood, learning is more likely to change through dialogue and reflection than through lecture and imposition. Science educators are restoring these time-honored practices to a central place in teaching and learning.

In a science classroom that encourages students to construct understanding through scientific inquiry, questioning plays different roles during distinct phases of the learning process. An initial question posed by the teacher or raised by a student — Why are there waves in the ocean? How is sound captured on a CD? — can set learning in motion and induce the class to conduct an experiment. Often the best questions are open-ended, allowing for more than one correct answer. In the investigation stage, additional questions from the teacher and classmates — What exactly are you doing? What would happen if you changed this? — help students see different routes to a solution and spur subsequent exploration and new hypotheses. When students are ready to propose explanations, questions help clarify, justify, and in some cases alter their thinking: Did anything you discover surprise you? What do you have to say about Linda's answer? A concluding round of questions — Where could you get more information on this topic? — can stimulate students to act on what they have learned.

***Learning often occurs when students are pressed to explain their ideas in ways that their peers will understand and to defend their viewpoints.***

Discussion is essential in a student-centered learning environment. Learning often occurs when students are pressed to explain their ideas in ways that their peers will understand and to defend their viewpoints. Feedback is an important component of discussion. To be effective, feedback must include more than the right answer; it should also include analysis and suggestions. Listening is critical, too. Teachers can gauge students' thinking processes by listening to their explanations; students can build new understandings by listening to other people's strategies and listening to feedback about their own. Questioning and discussion have the added bonus of strengthening students' oral communication skills.

Effective science programs also reserve time for reflection. One study found that learning increased when high school teachers provided about two minutes for reflection out of every ten minutes of discussion. Time for reflection enables students to consider feedback, make adjustments, and reformulate solutions.

# *What role can writing play in good science instruction?*

Scientists who write well are a treasure in the world of science. Their ideas travel farther and wider, and the clear expression of their mental connections enthralls colleague and layman alike.

Writing serves a similar function in the science classroom. When students are asked to write about their observations, results, reasoning processes, or attitudes, they are forced to pay closer attention to details, organize data more logically, and structure their arguments in a more coherent way. In the process, they clarify their own understanding of science and hone their communication skills. Moreover, science presents an almost inexhaustible choice of subject matter for the different forms of writing students need to master: description, exposition, persuasion, expression, narration, and poetry.

The potential of writing is too often underutilized in existing science programs. According to one survey, 60 percent of participating seventh graders and 41 percent of eleventh graders said they never had to write up the results of a science experiment.

***...science presents an almost inexhaustible choice of subject matter for the different forms of writing students need to master...***

Research and practice suggest a range of effective writing activities for the science teacher. Among them are:

- Have children keep a science journal in which they record observations, reasoning processes, and feelings.
- Require students to maintain a laboratory log in which they keep track of observations, approaches, results, and hypotheses and reflect on their experiences and findings. The log might also describe how the knowledge gained from experiments was applied to homework or used to solve everyday problems.
- Have children describe in detail an animal observed on a class trip to the zoo.
- Assign an essay convincing other children to recycle trash.
- Encourage students to write letters to the editor of the local paper supporting or opposing the city's decision to cut the budget for the science museum.
- Ask children to write a poem or a story based on their feelings about Hurricane Andrew.

# *What are some effective ways to integrate science with other areas of the curriculum?*

Curriculum integration experiments have been tried on and off over the past few decades, sometimes successfully, sometimes not. The less effective programs tended to "sample" bits of content from different fields without giving students enough meaty content in any one subject. Other projects were not well constructed in terms of scope and sequence.

As science vies with other fields for time in a limited school day, educators, researchers, and scientists have been taking a fresh look at how to integrate science with other curricular subjects in ways that avoid these pitfalls. (For purposes of this discussion, integrated programs are those that connect with fields outside of science, as opposed to interdisciplinary programs that coordinate disciplines within science.) Research cautions, however, that curriculum integration must be implemented carefully so as not to oversimplify or water down science content.

Some researchers contend that integrated learning activities are more viable and attractive at the elementary level because they require fewer scheduling changes and can be done by one teacher. Even so, middle schools and high schools can integrate instruction effectively if they are willing to be flexible about scheduling, planning, and classroom organization.

***Good models exist for integrating science with mathematics, language arts, social studies, history, physical education, and fine arts, among others.***

Curriculum integration does not always mean fully merged courses. Other successful approaches include integrating units designed cooperatively and taught in parallel or by a team of teachers, clustering of similar disciplines, and coordinating topics among otherwise separate departments.

Good models exist for integrating science with mathematics, language arts, social studies, history, physical education, and fine arts, among others. Mathematics and science are natural partners with similar goals of building process and problem-solving skills. Math serves as a critical tool for studying science. Science provides real-life situations in which children can apply the abstractions of math. For example, they can measure and compare the distances objects travel, graph water temperatures, or calculate the percentage of red-haired children in the class.

Language arts is another compatible partner. Reading, writing, and oral communication are integral skills in science teaching and learning. Science, for its part, offers engrossing subject matter for children to read and write about in language arts classes. In an integrated model, students might read biographies of great scientists or write descriptions of science field trips.

The connection between science, technology, and society is a hot issue in the reform of science education. Science teachers who are intrigued by this approach might find enthusiastic allies in the social studies department. The study of such issues as whether the federal government should fund a superconducting super collider provides provocative learning opportunities in both subjects.

The history of science and technology contains fertile and challenging content for integrated instruction in science and history. Such topics as the development of great scientific ideas in world culture help students ground the concepts of science and see how ideas change over history.

***Such topics as the development of great scientific ideas in world culture help students ground the concepts of science and see how ideas change over history.***

Other creative couplings abound. A project in which students make leaf rubbings pairs science and art. An activity in which children build stringed instruments and alter their pitch teams science and music. Contemporary issues in biology, such as how a retrovirus works, link closely with health. Some schools are integrating several subjects through thematic learning. One model project on rivers, for example, suggests activities for science, language arts, math, social studies, technical education, and more.

Still, there are several challenges to be overcome in integrating instructional programs. One big challenge is providing adequate teacher training. Another is achieving a consensus among disciplinary specialists about goals, content, and pedagogy. Yet another is compensating for the lack of appropriate materials, although that situation is improving as schools, researchers, and professional organizations continue to work on developing quality programs.

# *What is the relationship between science education and technology education?*

Current science programs seldom distinguish between science and technology or present technology as a subject for study. When technology does come up, it is usually defined as applied science, a characterization that is incomplete and inaccurate.

Expert panels assert that in light of the major role technology plays in shaping the world, it deserves a more prominent place in school science programs. When technology and science are taught in tandem, they can extend and reinforce each other. Some research proposes a revised view of the relationship between technology and science, which clarifies that science proposes explanations for questions about the world, while technology proposes solutions for problems of human adaptation. Other experts suggest presenting technology as a practical mode of inquiry that directly addresses the issues humans confront on a daily basis. In this view, scientific theories and principles provide the knowledge which enables technology.

In a progressive instructional program, teaching would address both science and technology in a way that emphasized their interdependence but also clarified their differences. Strategies for solving technological problems and methods of scientific inquiry would be treated as distinct, though closely related, processes.

***Strategies for solving technological problems and methods of scientific inquiry would be treated as distinct, though closely related, processes.***

For example, students might examine real-life situations like the following that show how scientific concepts, technological solutions, and social issues interrelate:

Mr. McMillin, a high school biology teacher, asks his students to read an article from a science magazine that he found exciting. The article concerns the ways in which scientists, technicians, business leaders, and medical professionals have worked together to find a promising remedy for a terrible disease known as *onchocerciasis*, or river blindness, which is endemic to certain parts of West Africa. River blindness is caused by parasites. Initial efforts to fight the disease focused on using biologically degradable insecticides in strategic areas to eradicate the flies that carried the parasites. As this spraying program got underway, researchers independently began to consider that a drug called ivermectin, developed to combat livestock parasites, might be effective. After a limited trial, it turned out, one pill of ivermectin a year was found to inhibit the development of larvae in the body and safely protect infected people from the disease's worst symptoms, including blindness. The drug's manufacturer, Merck & Company, Inc., has been providing annual doses of the pills free of charge for all human treatments, as long as needed.

After students read the article, Mr. McMillin might initiate a discussion by inviting students to think about how they would have designed a research program to find a solution for river blindness. Students might discuss and weigh a whole range of issues. Among them are the social, economic, and other effects of generations of river blindness on the society of West Africa; the possible effects of some insecticides on the environment; the risks and benefits of testing drugs on people; the potential side effects of new drugs; the scientific concepts that underlie the two approaches for eradicating the disease; and the costs and benefits of a company providing free medication.

***Some schools are using "science-technology-society" curricula that help students explore social issues related to science and technology...***

One approach advocated in the research literature is the implementation of the "science-technology-society" curricula. Using this "science-technology-society" curricula helps students explore social issues related to science and technology and analyze short- and long-term effects; alternative actions; and the role of personal, governmental, and private sector decisions. Studies suggest that these approaches effectively engage students because the issues studied are ones they know and care about. Among the ideas explored are the ways in which scientists may use the same data to arrive at different positions; the influence of society on science research and technological development; and the limits of science and technology.

Developers and practitioners who have used these approaches contend that they more accurately represent the ethos of science than do the typical science strategies, and that they help students develop inquiry and literacy skills in context. In addition, they note, students who learn to use these approaches will be better prepared to resolve personal and social problems.

# What role can educational technology play in effective science instruction?

Young people who plan to enter scientific and technical fields will need a more sophisticated understanding of technology than ever before, but they are not the only ones. The ability to use technology effectively is becoming one of the new "workforce basics" for people in all fields.

The potential of computers, audio/video and communications technologies is underutilized in most science classrooms. One study found that about 36 percent of science classes in grades 10 through 12 used computers, most frequently for drill and practice, simulations, and laboratory work. The level of use appears to be lower at the middle school and elementary levels. According to another study, over 85 percent of students in middle schools never use computers. When computers are used, they are used most commonly as enrichment rather than as an essential part of science education.

***One study found that only five to ten percent of computer use in high school is for science, and only one percent in elementary school.***

Equity in technology is also an issue; the best instructional programs involving technology generally do not reach the schools that have the greatest educational need for them, largely because of costs. Evidence also suggests that even when the technology is available, science is a rather low priority for its use. One study found that only five to ten percent of computer use in high school is for science, and only one percent in elementary school.

Some schools are, however, taking advantage of the promise that computer and video technologies hold for science education. And, though not conclusive, studies suggest that these technologies, when used well and imaginatively, can increase students' interest and improve achievement, particularly for both the most advanced and the least advanced students.

Research further finds that the best applications of technology are interactive and give learners more control over their own instruction in an open and non-judgmental environment. Computers are particularly suitable for problem solving and group work. By contrast, when technological tools are used for drill and practice, they can reinforce negative views of science as static and dull. The effectiveness of instructional technology is also compromised, no matter how it is implemented, when the rest of the classroom environment remains the same.

The technology itself also provides a challenging topic for study, i.e., learning how computers or interactive video work. Since technology, as one report noted, is the eyes, ears, and muscle of science, an effective science program should strengthen students' knowledge of technological processes and help them attain proficiency in their use.

For more schools to make effective uses of technology in science teaching and learning, they need sufficient and appropriate hardware and high quality, easy-to-use software. They also need teachers who have been trained to use technology enthusiastically and competently and administrators who are open to new classroom organizations and instructional modes. Special care must also be taken to ensure that computers do not reinforce existing stereotypes and that girls, minority students, and children with disabilities are encouraged to learn about and interact with technology in the science program. Fulfilling these needs costs money, but this is an area where private sector and community support can be helpful and appreciated.

***Since technology, as one report noted, is the eyes, ears, and muscle of science, an effective science program should strengthen students' knowledge of technological processes and help them attain proficiency in their use.***

# How do textbooks affect science instruction?

***Some studies recommend using textbooks in a different way — as references rather than curriculum guides.***

Textbooks are by far the predominant instructional material in science education. The vast majority of science teachers use published textbooks to determine the topics they cover (or don't cover), to organize lectures, to assign homework, and to provide test questions and problems. And this, according to researchers, is part of the reason why science teaching and learning is in need of reform.

Many studies have analyzed the ways in which science textbooks drive curriculum and instruction. The consensus is that the use of textbooks generally reinforces less effective teaching methods and contributes to the image of science education as a dull, passive, and fact-oriented enterprise.

Studies have found that the most frequently used texts share several shortcomings. Most cover an encyclopedic range of topics in a cursory and somewhat disconnected way, impeding students' progress toward deep understanding of the core ideas of science. As new scientific information becomes known, editions become weightier and the coverage of topics more superficial.

The content in texts aimed at less advanced students is even more watered down. Some popular textbooks have also been criticized for being unclear, misleading, or even inaccurate. Pressures from special interest groups have resulted in modified treatment — or no treatment — of "sensitive" topics such as evolution, human reproduction, and a host of ethical issues.

Format can be a problem, too. Most textbooks use an overabundance of technical vocabulary and emphasize memorization of facts and generalizations rather than inquiry and thinking skills. Illustrations and other visual aids — a powerful communicator of information — are sometimes quite good, other times not.

Textbooks are likely to continue to play a central role in science instruction in the near future. Since textbook development takes time, and since publishers are unlikely to make major changes unless the market demands them, what should science educators do? Some studies recommend using textbooks in a different way — as references rather than curriculum guides. Teachers should supplement textbooks with a variety of printed materials, such as trade books, magazines, biographies of scientists, and good science fiction. Non-print materials such as bulletin boards and hands-on objects are also alternatives. Some new science curricular models use no textbook at all, but a variety of other primary source material. Districts may also consider purchasing different types of science textbooks to draw upon as resources and to permit students and teachers to compare and contrast different treatments of scientific concepts.

Some analysts recommend that educators, policymakers, scientists, researchers, and publishers work together to improve the quality of textbooks and promote the use of additional curriculum materials. Encouraging more working scientists, not just academic scientists, to serve as authors and review textbooks in the developmental stages is another recommendation.

States are very important players in the improvement of textbooks because several states have statewide textbook adoption policies. Some states have already tried to improve the procedures for adopting science curriculum materials. Twenty-two states adopt textbooks after reviewing to see whether they are aligned with state curriculum frameworks for science. California has gone still further by adopting multimedia materials for science, including those not in textbook form, and a multimedia curriculum for grade seven science. There are still many states and local districts, however, that have not set standards for textbook adoption that are consistent with the most effective approaches for science teaching and learning. Until more do, publishers will have less incentive to develop superior products.

***Some new science curricular models use no textbook at all, but a variety of other primary source material.***

# *Why are tangible objects and laboratory materials so important in science programs?*

The criticisms of textbooks and the movement toward active learning have spurred the use of a variety of materials, objects, and equipment as instructional resources. Laboratory experiences and projects are also integral components of good science instruction.

The range of potentially effective materials and equipment is limited only by the imagination. Students can learn science from the most humble objects or the most unusual materials; from reusables or consumables; from quality literature or stimulating visual media; from standard science tools, such as microscopes, and from ordinary consumer goods, such as a camera.

Several studies give high marks to the use of tangible objects, called manipulatives, that children can interact with physically as they seek to make sense of science concepts. Good instruction not only introduces new materials but also encourages students to create their own learning resources, such as models, simple machines, drawings, journal entries, or computer simulations as a way of representing concepts or thinking through problems.

Some research has found a positive, though not necessarily causal, relationship between students' use of science equipment and proficiency in science, especially at grade 11. Direct, hands-on experiences produce lasting memories, according to some studies.

***Direct, hands-on experiences produce lasting memories…***

Similarly, research has found that lab experiences can inculcate positive attitudes toward science. Labs are also effective places to develop manipulative skills, inquiry, problem -solving ability, and respect for precision, accuracy, and safety. For these reasons, some science panels recommend that all students in middle and high school should have daily or frequent access to science labs.

Access to laboratory work and hands-on materials is far from universal. Nearly 40 percent of science classes report using no materials at all. Only six percent of science classes in grades four through six have access to labs or special science rooms. In one survey, teachers and principals ranked inadequate facilities and a lack of funds for equipment and materials as very serious problems in science education.

An ongoing problem is the resource inequity between advantaged and disadvantaged schools. Affluent schools with advantaged students tend to have more, and better quality, instructional resources, ranging from laboratories to computers to well-stocked libraries. For example, rural and urban elementary science classes are nearly twice as likely as suburban ones to have a classroom with no science facilities.

One study showed that only 46 percent of seventh and eighth grade teachers reported having access to a general purpose lab, and only 64 percent of eleventh grade teachers reported access to a specialized science laboratory. In fact the use of laboratories for biology instruction has actually declined; the reasons cited include decreasing school equipment budgets; more time spent by teachers on textbook learning; scheduling problems and short periods; maintenance demands; and a lack of teacher preparation. Logistical considerations, such as large classes and lack of space, seem to be a common obstacle to laboratory work in all science disciplines.

***...rural and urban elementary science classes are nearly twice as likely as suburban ones to have a classroom with no science facilities.***

Equipment and materials do not always have to be purchased commercially, however. Community institutions, including some of the top science museums, have developed good modular science kits, which include teacher guidance, student activity books, and equipment. There is also enormous untapped potential in such household objects as plants, cooking staples, or ball bearings, or such outdoor materials as rocks and insects. Schools might also look to parent, community, and private sector sources, as well as science, environmental, and other professional societies, for free or inexpensive publications and materials.

# How can teachers use whole environments to teach science?

Educators are beginning to realize that one of the richest tools for teaching science lies right outside the schoolroom door, and that is the diversity of environments that make up our world. An environment in this context can mean a distinct ecosystem like a salt-water marsh, or a man-made environment like the city dump. It can cover the expanse of a national park or be a small garden wedged behind a rowhouse. Even the school itself — its physical plant, grounds, and human services — could be considered an environment for purposes of study.

***Whole environments present incomparable opportunities for helping students realize that their world actually contains millions of smaller worlds.***

Whole environments present incomparable opportunities for helping students realize that their world actually contains millions of smaller worlds. They begin to see environments in new ways and notice new things in familiar places. The study of environments also presents unique chances for students to interact with people who "do" science and technology in real-life settings.

One example of the use of environments to teach science is Project Lifelab, which has been funded by the National Science Foundation and disseminated by the U.S. Department of Education's National Diffusion Network program. In this project, students and teachers create a vegetable garden environment that helps children learn about nutrition, earth science, and life science.

The study of environments does not have to be limited to earth and life sciences, although these are certainly rewarding options. Technology, so well represented in an urban setting, offers challenging opportunities for students to understand complex relationships among science, the environment, and human society. Similarly, both pristine environments and disturbed environments provide interesting subjects for discussion, reflection, and learning.

# *What role does assessment play in effective science instruction?*

Assessing student progress and instructional quality is an important part of science education. One thing must be made clear from the outset: assessment encompasses more than testing, and much more than standardized testing. It includes such techniques as systematic teacher observation and so-called "authentic" assessment, in which the tasks assessed more closely parallel the learning activities and outcomes that are desirable in the science classroom.

Assessment fulfills many functions, from helping teachers make day-to-day classroom decisions to providing parents, the public, and policymakers with information about the overall effectiveness of a science program. In the classroom, most teachers use combinations of teacher-made or end-of-chapter tests and their own professional judgments for day-to-day instructional decisions. They use standardized tests for broader assessment purposes.

New approaches to science teaching and learning have expanded the role of assessment. Consequently, some teachers, schools, districts, and states are trying out a broader range of assessments and using assessment in new ways. For example, in an effective science classroom, a teacher might use assessment to fulfill any or all of the following purposes:

- Find out what students know and can do before instruction begins.
- Determine how they are progressing toward learning goals.
- Identify which strategies and thinking processes students use to reach answers or conclusions.
- Pinpoint which questions to ask to determine how well students are integrating new information.
- Establish what students have learned after a specific period of instruction.
- Motivate students.
- Inform parents about their children's learning.
- Evaluate the effectiveness of special interventions.

***New approaches to science teaching and learning have expanded the role of assessment.***

- Signal to students the areas in which they need to improve.
- Communicate teacher expectations about what is important.
- Determine whether they need to alter their teaching.

Schools, school districts, states, and the federal government also use assessment to monitor the effectiveness of teachers, schools, districts, and special programs, and to make policy decisions.

***When used simplistically or inappropriately, assessment can… negatively affect students' perceptions of themselves as science learners.***

Assessment can be a powerful influence on curriculum and instruction, for good and for bad. The format of the assessment and the uses to which results are put can guide how teachers teach and students study, especially when applied to "high stakes" decisions such as allocation of resources, admission to special programs, or receipt of a high school diploma. When used simplistically or inappropriately, assessment can drive teaching and learning in unhealthy directions and can negatively affect students' perceptions of themselves as science learners.

Many researchers have become deeply concerned that assessment is not being used well in most science education programs. Concerns center around whether assessment instruments, such as norm-referenced, standardized tests, are being used for too many purposes for which they were not designed, and whether the results of tests are being misunderstood and misapplied. Some researchers have asserted that the most common assessment formats, particularly conventional standardized tests, reinforce outmoded or ineffective instructional practices. For these and other reasons, many argue that assessment is an area of science education that is ripe for reform.

# How do standardized tests affect science teaching and learning?

Paper-and-pencil tests, typically standardized multiple-choice tests, are the primary assessment tools in most science classrooms. Standardized tests have advantages of efficiency for testing large numbers of students, and many people perceive them as a more objective and reliable measure of achievement than assessments that rely more heavily on individual human judgment.

Recently, however, standardized science tests have come under strong criticism. Many researchers argue that conventional multiple-choice tests are questionable proxies of science knowledge. Because they do not ask students to generate their own answers, the tests do not measure scientific thinking. And because they have a single right or wrong answer, they reinforce the misleading conception of science as a static body of facts. Further, they do not assess laboratory skills at all.

Many of the standardized science tests are norm-referenced, ranking individual performance against that of a larger group. This, too, concerns some analysts, who say it perpetuates the notion that only a few students — the top scorers — are smart enough to pursue science. Researchers also raise questions about how well standardized tests measure the performance of students who are outside the cultural mainstream.

Of even greater concern to many researchers are the ways in which standardized tests may drive instruction in less effective directions or affect children in negative ways. Some researchers contend that conventional standardized tests, by sampling a breadth of content in a superficial and unconnected way, actually reward instruction that drills students on low-level facts and name recognition. In a high stakes testing situation, some studies have found that it is not uncommon for teachers to give teacher-made tests that imitate the format of large-scale assessments. Even schools that have implemented many of the reforms described in this document find their efforts undermined when standardized test scores are what "count."

***Because they do not ask students to generate their own answers, the tests do not measure scientific thinking.***

Responding to these criticisms, researchers and test publishers are developing new forms of tests, including multiple choice tests that require students to justify their answers or that assess thinking processes, open-ended answer tests, and performance assessments.

# What are some good or promising methods of assessment being used in science education?

Aware of the limitations of conventional tests, researchers and practitioners are developing and implementing new forms of assessment that seek to better reflect the goals and processes recommended for effective science instruction, although these new assessments have their own weaknesses.

Several of these new forms fall under the umbrella called performance assessment, in which students create an answer or product that demonstrates their knowledge or skills. Many of these are hands-on in nature. Students might be asked to do a laboratory experiment or to solve a real-life problem. Through a series of systematized observations and questions, teachers or outside evaluators would observe and evaluate both the processes the students use and their understanding of the major concepts involved. In this type of assessment, students may work together or separately, using the equipment, materials, and procedures they would use in good, hands-on science instruction.

***Students might be asked to do a laboratory experiment or to solve a real-life problem.***

Another type of performance assessment that works well for students who are verbally or visually oriented is the presentation, which could be in the form of an oral presentation or a poster paper. This latter format mirrors the way many scientists present findings. Authors create posters explaining ideas; these posters might include graphs, photos, maps, or drawings, as well as some text. For example, students might develop a poster that explains how a local river evolved to its present state and how it might be protected.

A related form of assessment is systematic teacher observation, in which teachers scientifically observe and record student behaviors as they carry out meaningful tasks. Still another type of performance assessment being pioneered in science requires students to amass a portfolio of their work over time, which might include lab notes, science journals, and other written products, or graphs and charts of laboratory findings.

Research literature is also giving greater emphasis to student self-assessment and peer assessment techniques, in which students — for themselves or others — reflect on experience, attempt to understand what took place, and make judgments about what was learned.

Integrated computerized systems, which track and report student performance at the same time students are learning, is a growing approach to assessment. Paper-and-pencil tests are also being revamped to allow for more open-ended and student-constructed responses.

All of these assessments attempt to meet criticisms of current testing practices and to focus attention more on processes and thinking skills. Many of the performance assessment models meet the added criteria, emphasized in research literature, that assessment should closely resemble instruction and differ only in purpose. In addition, they provide much richer knowledge on which teachers can base instructional decisions.

Performance assessments have drawbacks, however. First, they require staff development for teachers who will implement, score, and use the results of the assessments. Second, they are considerably more expensive to administer than conventional tests. Third, they take more time from the school schedule to implement — some may last over several days. Fourth, although it is possible to standardize performance assessments to allow for comparisons among groups, it is a demanding process and is still in the experimental stages for many types of assessments.

Finally, it is difficult to correlate performance assessments from one task to another or to use performance assessment to project future student performance. And that is one major function of standardized testing.

***Many of the performance assessment models meet the added criteria...that assessment should closely resemble instruction and differ only in purpose.***

# How can science assessments be better linked to instruction?

Some researchers and educators look forward to the day when there will be a "seamless web" of instruction and assessment in which assessment is no longer be a distinct activity but is "built into" students' regular learning experiences, virtually indistinguishable from instruction. In this vision, students and teachers receive ongoing feedback as needed during the instructional process. Assessment for classroom purposes (as opposed to external monitoring purposes) is a routine, non-threatening process.

***Assessment that does a good job informing instruction should have several features.***

This vision calls upon students, teachers, and administrators to look at assessment in a different way. Teachers must understand that the primary information will not be quantitative, but will provide a rich portrait of student strengths and weaknesses. In addition, assessment to inform instruction does not have to compare students to one another, which means that student approaches and responses to a problem may look very different and still be correct. Students, especially high school students, will be encouraged to be the primary users of assessment information in their own learning.

Assessment that does a good job informing instruction should have several features. It should measure the processes students use as well as the answers they reach. It should measure all of the goals of the curriculum, not just a few. It should address both group activities and individual ones. It should be developed by, or with ample input from, teachers and should include teacher professional observation and judgment. Perhaps most importantly, it should draw upon information from multiple assessment sources, including but certainly not limited to tests.

Finally, assessment to inform teaching and learning should have a strong self-evaluation component for both students and teachers.

# *What should teachers know and be able to do to teach science actively and effectively?*

Teachers are vital to the reform of science education. No reform, no matter how well-planned, will succeed unless it affects the special relationship between teacher and student.

A changing role for the teacher is at the heart of most of the reforms proposed for science teaching and learning. In the new paradigm of science education, the teacher is no longer the authority who imparts a fixed body of knowledge to students, but a facilitator and role model who gently guides students through the adventure of learning, encouraging them with questions and feedback and sharing their curiosity and excitement. One expert compared this revamped role of the teacher to that of an orchestra conductor, whose job it is to get things started, keep them moving, and coordinate the overall process.

***In the new paradigm of science education, the teacher is...a facilitator and role model who gently guides students through the adventure of learning...***

A consensus is emerging from research about some of the qualities, knowledge, and skills that teachers of science should possess. This process of consensus building is far from complete. Even so, many researchers and educators agree that the most effective science teachers are those who have some of the following personal attributes:

- They are learners themselves and are committed to improving their knowledge about science and science teaching throughout their careers.
- They are willing to learn from other teachers and resource people in their school.
- They have a vision for how they want to change their classrooms.
- They spend time reflecting on their own teaching practices.

In addition, to implement the model of active learning and scientific inquiry, teachers should know and be able to do at least the following:

- Understand the key concepts of science, how they developed through history, and how they relate to each other.
- Devise incisive questions.

- Choose materials and activities that are likely to lead to new discoveries and information.

- Model qualities they would like their students to have, such as curiosity and enthusiasm.

- Skillfully observe students' learning processes.

- Lead provocative and substantive discussions without lecturing.

- Be able to informally assess the development of understanding.

To empower all teachers to implement these roles will require a substantial and renewed commitment to preservice preparation and staff development.

***To empower all teachers to implement these roles will require a substantial and renewed commitment to preservice preparation and staff development.***

# *What resources and professional development opportunities do teachers need?*

Teaching is an art, as one observer put it, acquired slowly and carefully through mentors, self discipline, and self evaluation. Any effort to reform science education must recognize this and place teacher preparation and staff development high on the agenda for sustained attention and funding.

As statistics show, many teachers of science, especially elementary teachers, do not feel at ease in this role. According to one study, only 27 percent of teachers in grades kindergarten through six felt well-qualified to teach life science and only 15 percent felt qualified to teach physical and earth or space science — significantly fewer than those who felt comfortable teaching math or reading. Teachers who feel unprepared are likely to be "science avoiders," devoting less time to the subject than to other basics. At the secondary level, it is not uncommon to find science teachers teaching out of their field of certification. Even the best teachers with quality preservice preparation and recognized skill in the classroom still need opportunities to keep up with burgeoning science knowledge and promising instructional practices.

A major conclusion of reform panels is that schools and government must make a serious and constant commitment to staff development for classroom teachers throughout their careers. Staff development should be considered part of a necessary and ongoing continuum of preparation after preservice education, internships, and practice teaching.

What types of staff development are most effective? Research suggests that continuous and interrelated efforts are more effective than short-term, sporadic ones. A combination of activities addressing varying teacher needs is also advised. Many of these activities will be school-based and teacher-driven. For example, elementary teachers might need to spend time with other science teachers of demonstrated experience. First- and second-year teachers will need special assistance with plenty of opportunities for interacting with mentor teachers. Teachers in the same school might feel they need more collaborative opportunities to exchange views and learn from each other or the flexibility to organize classes in ways that take advantage of each teacher's respective background and skills.

Some teachers may also need out-of-school opportunities, such as paid sabbaticals to take courses updating their content

***Any effort to reform science education must ...place teacher preparation and staff development high on the agenda for sustained attention and funding.***

knowledge, or opportunities to attend teacher institutes in new science curricula or new scientific developments.

What should the methods of staff development be? First and foremost, experts recommend that teachers be taught as they are expected to teach — through an active, multi-disciplinary approach, rather than through self-contained lectures. This applies to inservice as well as preservice education. Teachers should also have frequent opportunities for hands-on interaction with equipment, materials, and technology. Furthermore, research has found that staff development works best when there is ample follow-up after the initial training.

What should the content of staff development be? This will vary according to teacher needs, but some of the areas of greatest need include staff development on implementing new assessment approaches, using technology well in the classroom, choosing learning materials and resources, and, of course, understanding and managing a more student-centered approach to learning.

***...the benefits of staff development are unlikely to be sustained unless schools become learning organizations in which good teaching can flourish.***

Finally, the research literature makes clear that the benefits of staff development are unlikely to be sustained unless schools become learning organizations in which good teaching can flourish. This means providing teachers with sufficient resources and materials, providing release time for teacher learning activities and student field trips, promoting collegiality, giving teachers more decision-making authority in school processes, and addressing logistical issues such as scheduling and classroom organization.

# *How can community resources help prepare and upgrade teachers' skills?*

Businesses, museums, and other potential community partners are science-rich in many ways, especially compared with schools. Partnership programs can help direct the unique resources of science-rich facilities toward the important task of preparing, upgrading, and updating the skills of science teachers.

Businesses and community groups can provide several forms of support to teachers. One is access to a wealth of instrumentation, equipment, and materials that no school could afford. Imagine the excitement of a physics teacher visiting Fermilab for the first time, or a biology teacher joining a research ship of scientists on an expedition to the Galapagos Islands. Such opportunities are becoming more common as schools, businesses, and community institutions forge formal partnerships in science. Forward-thinking business and community partners will welcome the presence of a teacher who wants to become familiar with their resources, perhaps with an eye toward developing a project for his or her class the next semester. In fact, several community institutions — museums, national parks, and government laboratories, for example — have developed formal programs to open their resources to teachers.

Another resource comes in the form of scientists, engineers, and other professionals and technical personnel. These personnel can conduct staff development, serve as science mentors for teachers, or consult on curriculum development and other issues. By forging relationships with working scientists, teachers can lessen their isolation from the broader scientific community and learn better ways to connect school science with up-to-date, real-world experience. Sometimes it can be difficult for teachers to gain access to scientists, but this can be overcome by working through an alliance or partnership that is already committed to improving science education and has a cadre of people who are willing and eager to work with schools. Furthermore, people with scientific and technical expertise are located in many different divisions of the same organization or business, or are found in many different occupations. If the first person who comes to mind is not available, it is possible someone else may be keenly interested.

***By forging relationships with working scientists, teachers can lessen their isolation from the broader scientific community and learn better ways to connect school science with up-to-date, real-world experience.***

Private sector and community partners provide a broad range of activities for teachers. Some provide fellowships, internships, or paid summer jobs that enable teachers to become part of a scientific or technical team; teachers in this setting can learn about new scientific developments and acquire new collaborative skills. Some partners lend training materials and equipment. Some organize short-term field trips or scientific expeditions or conduct pre-visit staff development before a teacher brings the whole class. Still others conduct full-scale workshops or summer programs centered around the partner's special resources and expertise. In addition, more and more communities are forming voluntary advisory groups that foster two-way communication among teachers and community science leaders.

Universities can be an especially valuable partner. In addition to the obvious coursework and staff development opportunities they offer, universities can provide all the other forms of support mentioned above.

It is essential that teachers be involved in designing the content, strategies, timing, and other features of these opportunities.

Teachers make their own contributions to a partnership program. They can help business and community people understand what works in the classroom and advise them about the type of support that would be most helpful and welcome. They can also help community people who are unaccustomed to school bureaucracies gain access to the system, understand school policies and personalities, and work out ways to accomplish their goals.

***It is essential that teachers be involved in designing the content, strategies, timing, and other features of these opportunities.***

## What We Know About Science Teaching And Learning

# EDTALK

# Science in the Home and Community

# *How do parents' attitudes affect children's science achievement?*

In the discussion of science curriculum reform, it should not be forgotten that a child's first teachers are the many adults — not just parents, but other relatives as well — who surround, mold, and direct the child's initial years. By the time school begins, parental attitudes carry such weight that notions about a child's first subjects, like science, affect how well the child will perform as a student. In fact, research has shown direct links between parental attitudes and student achievement at all grade levels. One study of winners of the Westinghouse Science Talent Search, one of the oldest high school science competitions, suggested that parents and close relatives, along with teachers, played critical roles in their children's decisions to pursue science.

Unwittingly, parents can send discouraging messages about science, such as "they were never good at science themselves," or scientists are "nerds or geeks." Worse, when parents impart their own fears of science and technology, children's expectations about their ability to do science may suffer, along with their sense of the importance of science class. Down the road, this makes it less likely that the children will give serious consideration to a career in science.

The widespread attitude that success in science depends on "ability" rather than effort can negatively affect student learning. Parents who hold this belief are less likely to require their children to spend time on homework or to encourage them to participate in after-school activities.

Parent apathy about science is another reason why students do not perform that well in science, according to some research. One survey found that one-fourth of the parents of tenth-graders thought that one or two science classes in high school was enough for their child. And 57 percent of the tenth-graders said that their parents did not think science is a very important subject.

Although changes in society may have improved attitudes about girls' achievement and role in science, research suggests that girls are more influenced by negative parent signals about science than boys are. This, in turn, can discourage girls from pursuing advanced education or a career in science. Parents — along with peers, other adults and the media — may give females the idea that only certain roles are appropriate for them.

***One study…suggested that parents and close relatives, along with teachers, played critical roles in their children's decisions to pursue science.***

In addition, parents tend to interact differently with girls and boys in ways that make boys more interested in and better prepared for science education. Parents are more likely to encourage boys to build with blocks, tinker with machinery, and handle tools. Boys also tend to receive subtle rewards for taking risks, while girls are often praised for "being a little lady." Although good parent attitudes cannot eliminate all gender barriers a girl will encounter, they can go a long way.

Research also shows that regardless of how much money or education parents have, children achieve at a higher level and are better adjusted socially when their parents (and other family members) are involved and interested in their education.

Studies further confirm that when parents support teachers and get involved with the school, their children in all grades perform better. Participating in school activities and parent-teacher groups, talking regularly to the child's teachers, asking questions about the science program, chaperoning a science field trip, or volunteering in the classroom are just some of the ways parents can become involved in school.

***Although good parent attitudes cannot eliminate all gender barriers a girl will encounter, they can go a long way.***

# What activities can parents use to stimulate their children's interest in science?

Many parents feel that science is one area they cannot help their children with because they don't know much about it themselves. But parents do not need a degree in microbiology or engineering to help their children. All they need is the willingness to make an effort, to nurture children's natural curiosity, and to watch and learn along with them. Parents and families of all income and educational levels can support children's science learning in a variety of ways: by promoting science activities at home and in the community, leading family discussions, monitoring homework, setting aside time for reading and study, limiting television viewing, and encouraging children to take advanced science courses.

Children are naturally curious about the world around them, and this provides the perfect springboard for getting them interested in science. Normal questions children ask — How does a spider make a web? How does the furnace work? — can be used to help children think like scientists. Even if parents cannot answer the questions themselves, they can encourage children to observe carefully with all of their senses, write down what they observe, try to predict what might happen, test out different explanations, try to make sense of it all, and think about where they could get more information.

There are lots of fun and simple science activities — hands-on activities with everyday objects and materials — that parents can do in the home. For instance, letting children bake a cake can be a form of science learning as children measure out ingredients, examine the crystals in salt and sugar, and speculate about why cakes rise in the oven. Or children can grow crystals themselves with string suspended in sugar water — a rock candy treat. Observing the slow climb of colored water up a celery stalk over several days will teach not only capillary action, but patience. Bread molds, bugs, bubbles, balloons, and begonia plants can be used in the home to foster scientific habits of mind. Experts suggest that parents consider the child's interests and personality, and let children help select activities.

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Communities provide still more science activities that parents and children can do together, often free of charge. Almost all children love a trip to the zoo, or the dinosaur footprint exhibit at the museum of natural history, or the sky show at the planetarium. But even communities without formal science institutions are science-rich. A trip to a farm, a tour of the factory where mom or dad works, a hike in the woods, an afternoon at the library — all present opportunities for science learning. Science activities outside can be further enriched when parents and children talk about the visit ahead of time, discuss what they’re seeing while they are there, make repeat visits so that children can spend more time on what interests them, and engage in follow up activities at home.

Even when parents do not have time to accompany children themselves, many church groups or youth groups like Boy Scouts, Girls Scouts, Boys and Girls Clubs, 4-H, Y.M.C.A., and Y.W.C.A. have incorporated science activities into their programs.

Family discussions of news and current events with a science spin or a science television show can help children connect what they learn in school to happenings in the world outside. For example, a question about where hurricanes come from may result in parent and child getting out the atlas. Finally, discussion should also be a part of science-oriented family activities that take place outside the home.

Finally, it is important for parents to encourage their sons and daughters to enroll in challenging science courses all through high school. Regardless of how much education parents themselves have, they can let their children know that science knowledge is important in almost any career.

***Family discussions of news and current events with a science spin or a science television show can help children connect what they learn in school to happenings in the world outside.***

# *What is the role of homework in effective science education?*

Studies generally have found that the amount of time spent on homework correlates with student achievement, although it is hard to isolate the effect of homework from related factors, such as high student motivation and greater family support. Nevertheless, homework increases the amount of time spent on science learning, and research confirms that the more time students spend on a subject, the better they perform, especially in the early years.

American students do not spend much time on science homework. One-third of elementary students who received instruction in science said they spent no time on science homework, according to a 1986 national assessment. Two-thirds of the 13-year-olds in another science assessment said they did less than one hour of science homework a week. U.S. youngsters spend much less time on homework than international peers. One study found that children in Asian countries spent four to ten times as much time on homework as first graders in Minneapolis, and that disparities increased in later grades. Although the relationship between homework and achievement was not consistent across nations, the top three nations in one international science assessment also ranked highest on time students spent doing homework.

> ***...homework is most valuable when it is checked and discussed in the family or when parents help with homework.***

The quality of science homework is also important. One study found that 90 percent of homework in biology involves using the textbook, and textbooks in this subject have come under some serious criticism. Homework is also more effective when teachers check it and provide prompt feedback.

Research suggests that homework is most valuable when it is checked and discussed in the family or when parents help with homework. Parents should also monitor children's work habits and set aside time for studying or reading.

In summary, homework can be one of many valuable ways to complement classroom teaching and learning in science.

# *How does television viewing influence student achievement in science?*

Perhaps no issue divides educators like the question of television's effects on learning and achievement: to some it is an irredeemable villain, to others a powerful learning tool whose full possibilities have not yet been harnessed. Most agree, however, that regardless of curbs set by individual families, overall television viewing habits are not likely to decline, and this suggests the need for parents to monitor the quantity and quality of children's television viewing.

What are the effects of television on student achievement in science? There is some evidence that science achievement is not hurt by limited television viewing — up to about ten hours per week — but that as viewing time goes up, scores go down. One study found that students who watched six or more hours of television each day had poorer test scores in science than kids who spent less time in front of the TV. The problem is exacerbated when parents do not monitor what their children are watching, let children do homework in front of the TV, or allow children to watch TV late on school nights.

***There is some evidence that science achievement is not hurt by limited television viewing — up to about ten hours per week...***

Children can learn science from watching television, although the quality of science programming varies. Science programs are broadcast on network, public, and cable TV, if parents look for them, and some good science programs are available for rental on videotape. Parents can also point out science content in other shows, such as science stories in the evening news.

Educators advise parents to monitor the quantity and quality of their children's television watching and, where possible, to watch and discuss educational programs together with children. Such strategies as setting a viewing schedule, consulting with teachers, and using TV as a springboard to family discussions or involvement in off-screen science activities can be effective.

It is important, too, that parents take note of and try to counteract the negative messages about science and scientists that pop up so often on television. By the same token, it is incumbent upon educators and scientists to correct misleading media reporting about science and negative stereotyping about scientists.

One final point for parents to remember is that time spent watching television is time not spent on more active or higher quality endeavors.

# *What kinds of private sector and community partnerships foster science education?*

Schools, the private sector, and community institutions and organizations have mutual and compatible interests in improving science teaching and learning. Schools want to do the job they were created to do as effectively as possible. Businesses want young workers who have a high level of knowledge and skills. Communities need citizens who are scientifically literate to maintain their economic vitality and improve their quality of life.

Recognizing these interests, and realizing the synergistic effect that comes from group action, communities across America have begun forming public and private sector alliances or partnerships to promote reform and improvement in science and technology education. Although these alliances currently represent a very small proportion of the total investment in science education, they are producing results that have a strong ripple effect beyond the dollars expended.

Some of these partnerships are wide-scale collaboratives that coordinate science education improvement for an entire state or region. Others are organized around a city or school district. Some initiatives are spearheaded by national organizations but carried out and adapted at a local level. Still others are one-on-one relationships between a school and a business, or a school district and another community partner.

The range of partners is as broad as the community itself. Private sector partners might include large corporations, small businesses, private laboratories, trade associations, unions, self-employed individuals (farmers, consultants, writers), and Chambers of Commerce. Within the participating businesses, any employee could make a contribution, from the CEO to a computer programmer to a bench scientist.

*The range of partners is as broad as the community itself.*

Community partners might include museums, zoos, libraries, government laboratories and research centers, military installations, municipal authorities, science centers (e.g., aquariums, planetariums, botanical gardens), parks, community-based organizations, scientific organizations, professional associations, religious, social, and benevolent clubs, and many more.

Education partners may include state and local school boards, public and private school administrators and teachers, teacher unions, professional education associations, technical schools, colleges and universities, and parent groups.

Partnership programs bring several benefits to a community. They provide a vehicle for joining the "science rich" private sector with the sometimes "science poor" public schools. They also broaden the base of public support for schools as schools make difficult but necessary reforms in their science education programs. For example, some business people have been among the most vocal critics of public schools, yet many who work directly with the schools have come to realize the challenges that schools face and that producing a highly skilled workforce is a shared responsibility. And because outside partners do not have to comply with all of the regulatory and funding restrictions and political constraints to which schools are subject, they can sometimes be more innovative in their approach to reforming science.

***Although monetary resources are important, alliances can offer other forms of assistance that are equally valuable.***

Although monetary resources are important, alliances can offer other forms of assistance that are equally valuable. Human resources are among the most important: a participating scientist is a golden contribution. Other contributions are equipment, technology, and exposure to cutting-edge science.

Groups that have experience with alliances have identified several factors that contribute to the success of these partnerships. Among them are the following:

- Healthy partnerships have a coherent philosophy, mission statement, goals, and action plan.

- Partners plan, implement, and evaluate their efforts together.

- The organizational structure is flexible enough to change with emerging needs and allow maximum communication between members.

- Successful alliances design reforms with an awareness of the needs of education as a whole and the demands of educational management and policy.

- Alliances should continually monitor and assess their progress.

# How can businesses and community agencies become involved in science education?

Businesses and community organizations and institutions possess a wealth of physical, educational, human, and financial resources for science learning that most schools do not have. Museums and zoos have exciting, accessible, hands-on experiences that can make science come alive in a way it cannot in classrooms. Industrial laboratories have technology, equipment, and applications not available to schools. Observatories have scientists pushing the frontiers of knowledge. Scientific professional societies have expert people who want to give something back to their professions by helping young people. And then there are corporations that have the budget and commitment to invest in their communities.

Research has found that out-of-school science activities are highly correlated with science learning. There are many types of experiences and programs that businesses and communities can provide to stimulate and enhance science education. Some address students, some teachers, and others broad, systemwide reform.

One obvious type of learning experience is a class trip. The stereotype of the once-a-year class trip to a museum, where quiet children look at (but don't touch) glass cases filled with stuffed animals and their preserved habitats are becoming more and more a thing of the past. Today's museums and science centers are shifting their emphasis from display to active, hands-on involvement by visitors, with buttons to push, problems to solve, and technology to interact with. Industries, farms, national parks, and other places that invite hands-on learning are also appropriate.

***Many community institutions are striving to become adjunct "learning centers"...***

Many community institutions are striving to become adjunct "learning centers" to schools, in which they develop curricula for use in schools that coordinate with their exhibits and activities and provide pre-visit training for teachers. Thus, a class visiting a museum or science center might have a specific assignment to complete.

Some community partners and businesses provide funding resources for school science. One project, for example, makes "mini-grants" of up to $500 to single science teachers or up to $10,000 for group science projects to improve teaching. Others buy or lend surplus laboratory equipment and other materials. Sometimes what a school really needs is "glue money" to pay the salary for someone to coordinate partnerships and resources. Still another valuable activity is to provide support for public awareness campaigns.

Other partners provide people and expertise. Scientists and other technical personnel might volunteer to serve as mentors, consultants, curriculum developers, proposal writers, tutors, guest lecturers, club sponsors, contest judges, and adjunct teachers. Second career and early retirement programs allow experienced and willing personnel to get involved in science education to an even greater degree. Some states are paving the way to make this possible. New Jersey, for instance, has an alternative certification program to enable people with expertise gained from other careers to enter the teaching profession.

Promoting careers in science is an important area in which partners can make a real difference. Career days that bring in a range of employees from all fields of business can demonstrate the connection between high school science and future jobs. Frequent speakers and mentor programs can make this same point. Some districts have worked together with business to develop magnet schools in science. Businesses might also help schools with job placement for graduates.

Although the number and range of community learning opportunities has mushroomed, not all schools take advantage of them. In one survey, over 50 percent of the third graders and more than 80 percent of the seventh graders reported never going on a field trip with their science class.

***Second career and early retirement programs allow experienced and willing personnel to get involved in science education…***

# *How can businesses and community groups encourage girls and minority students in science?*

Businesses and community groups are among the leaders in current efforts to encourage more girls and minority students to study science and consider science careers.

Private and public sectors have one considerable asset: role models. Female and minority students meeting, talking with, or becoming friends with successful people of their own gender, race, or ethnicity, is a powerful motivator for science learning. Individuals other than just scientists, engineers, and technical personnel can be role models. People like physicians or successful business proprietors can also speak to the importance of science in their careers and give students the vision to overcome obstacles in their own lives.

***Some museums and science centers employ high school "explainers" who are minority students.***

Several businesses, community organizations, and government agencies have set up programs that pair girls or minority youngsters with volunteer science mentors. Mentors may engage the student in research, provide tutoring or enrichment, or just get together and talk. Other programs bring women and minority professionals into schools, girls clubs, community centers, and other settings to talk to young people. In some cases, these role models also lead hands-on science activities.

Another resource that businesses and community groups can provide is exposure to cutting-edge science or technology through enrichment programs. One such program assigns minority students a tutor — usually an African-American engineer; together students and tutor do such activities as robot building, telephone building, and computer simulations. Other programs make special efforts to recruit girls and minority students for summer, weekend, or after-school enrichment activities.

Modelling is another effective approach to equity. Some museums and science centers employ high school "explainers" who are minority students.

Other businesses and community groups provide internships to underrepresented students that enable them to study or work in industry, government laboratories, or museums and other institutions. Several businesses and professional organizations also sponsor scholarships that enable female and minority young people to pursue college or graduate work in science.

# *Where can parents, business leaders, and community people get more information?*

Communities with a serious commitment to improving science education for their children may want to read the major reports and studies produced by the scientific, education, and business groups that have been leaders in the reform of science education. Among the "must" readings for those who want more information are the following:

*Science for All Americans* (1990). Published by Oxford University Press; originally produced by the American Association for the Advancement of Science, 1333 H Street NW, Washington, DC 20005. This report contains a detailed set of recommendations on what understandings and habits of mind are essential for citizens in a scientifically literate society.

Several reports published by the National Center for Improving Science Education, 1920 L Street NW, Suite 202, Washington, DC 20036, among them, *Getting Started in Science: A Blueprint for Elementary School Science Education* (1989); *Getting Started in Science: A Blueprint for Science Education in the Middle Years* (1990); and *The High Stakes of High School Science* (1991). These reports contain concrete policy recommendations for improving science curriculum and instruction at three different levels of education.

*Scope, Sequence and Coordination of Secondary School Science, Volume 1, The Content Core* (1992). National Science Teachers Association, 1742 Connecticut Avenue NW, Washington, DC 20009. This draft report contains guidance on designing coordinated curriculum for secondary schools.

*A Guide for Building an Alliance for Science, Mathematics and Technology Education* (1991). Triangle Coalition for Science and Technology Education, 5112 Berwyn Road, 3rd Floor, College Park, Maryland 20740. This report provides practical guidance for community organizations and individuals that want to build alliances to improve science, mathematics, and technology education.

*Science Learning Matters: An Overview of The Science Report Card* (1988) and *A World of Differences* (1989). National Assessment of Educational Progress, Educational Testing Service, Rosedale Road, Princeton, NJ 08541. The first report highlights key findings from the National Assessment's studies of U.S. student achievement in science. The second one compares achievement of the U.S. and other countries in science and mathematics.

***Communities with a serious commitment to improving science education for their children may want to read the major reports and studies produced by the scientific, education, and business groups that have been leaders in the reform of science education.***

*Science for Children: Resources for Teachers* (1988). National Academy of Sciences and Smithsonian Institution, Room 1201, Washington, DC 20560. This report, now being updated, is a catalogue of curriculum materials, supplementary reading material, and resource centers and organizations for improving elementary science education.

*Science Education Programs That Work.* U.S. Department of Education, 400 Maryland Avenue SW, Washington, DC 20202. This report describes new science curricula for elementary and secondary schools.

*Changing America: The New Face of Science and Engineering* (1989). The Task Force on Women, Minorities, and the Handicapped in Science and Technology, National Science Foundation, 1800 G Street, NW, Washington, DC 20550. This report makes recommendations for improving education for all students.

The list of references at the end of this document contains a host of publications addressing every aspect of science education reform. In addition, the regional educational laboratories have information about teaching and learning science.

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